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A paper presented at the 19th Annual Convention of the American Institute of Electrical Engineers, Great Barrington, Mass., June 19th, 1902.

NOTES ON THE PLOTTING OF SPEED-TIME CURVES.

BY C. O. MAILLOUX.

The most practical way at present known of studying and analyzing electric railway problems, is by means of curves depicting the relation between the various factors or quantities which influence the conditions or affect the results, and showing how these factors and quantities vary with respect to each other or with respect to the time, the speed, the electric energy, or some other determining feature or circumstance of the case.

The precise determination of most of the important factors entering into the problem in any specific case, for instance, the electric power input, energy consumption, capacity and characteristics of motor equipment, station equipment required, heating of motors, line losses, etc., etc., for a given electric railway service, involves the general problem of not only determining what actually does take place, but also of predetermining what may, should and must take place, at every successive interval of the total time consumed in an average run between two successive stations or stopping points, or, what is still better, at every instant of time during the entire trip, with each kind of car or train to be used for and in the said service.

The speed-time curve is the key to the solution of this general problem. It is the important connecting link whereby the relationship between the various factors and quantities aforesaid is established and verified. It constitutes, in most cases, an important and essential—one may say, indispensable—preliminary step in the study and solution of new and complex electric railroad problems, for the reason that many of the factors involved can be determined or evaluated with precision only by its assistance, and could scarcely be determined at all without it.

The use of a curve substantially equivalent to a speed-time curve was suggested in connection with certain problems of steam locomotive propulsion, as early as 1890, in Godwin's "Railroad Engineers' Field Book." This suggestion was commented upon favorably in an article published in the *Railroad Gazette*, at the time, (Volume XXII, 1890, pp. 731-732). It does not appear, however, that much, if any, practical use was made of this idea in subsequent discussions of railway problems. It is only within the last five or six years, and entirely owing to the efforts of electrical engineers to substitute rational for empirical methods in electric railroad engineering, that the speed-time curve has been thought of seriously or used practically in connection with electric railroad problems. The idea of thus using the speed-time curve seems to have suggested itself to, and to have been utilized by, several individuals, independently, at about the same time. It was used in January, 1898, by Mr. S. T. Dodd and the writer, who collaborated in the preparation of certain estimates, charts, data, etc., forming part of a report on an electrical equipment for the Manhattan Elevated Railroad of New York. The importance and the value of the curve were not generally understood or appreciated by electric railway engineers, however, until Mr. A. H. Armstrong read his able and interesting paper on "Some Phases of Rapid Transit Problems" at the Omaha meeting of this INSTITUTE in June, 1898. In that paper, the utility of the speed-time curve in the study of railway problems was demonstrated by Mr. Armstrong in a brilliant and convincing manner, and the curve has since become recognized as a very useful means of analysis in dealing with such problems.

Speed-time curves have been used in two different ways: first, as a method of approximation or generalization for the determination of rules and data pertaining to, and useful in, abstract or general cases; second, as a method of precision for the exact determination of rules and data in individual or concrete cases, and also as a criterion or test of their fitness for, and applicability to, such cases.

The process of plotting these curves is much less difficult and tedious in the first case than in the second case. The reason is that in generalizing or in dealing with abstract cases, the use of certain hypotheses or assumptions capable of simplifying methods is admissible; whereas, in dealing with an individual case, all hypotheses or assumptions not strictly consistent with

the actual facts of the case should be eliminated in order that the method may lead to correct and reliable results.

As might be expected, the speed-time curve is influenced and complicated by certain features and conditions characteristic of each individual case, which ought to be taken into account in order to attain accurate, reliable results. When properly plotted so as to truly represent all the factors which influence it, the curve becomes a valuable instrument of precision by means of which the practical results to be anticipated in the particular case under consideration, may be analyzed, checked, criticized and corrected with accuracy and confidence. These factors include the various constituents or components of that complex resultant called "train resistance," also the track gradients, track curvatures, train inertia (linear and rotational), capacity and gearing of motors, current limit, voltage, etc., etc. In dealing with a general case, however, the engineer may greatly simplify the task of assorting these influencing factors, and of assigning the proper value to each, by making assumptions regarding some of them. The usual process of simplification is to make one or all of the following assumptions: That the line is absolutely level and tangent (straight); that the train resistance is constant at all speeds; and that all runs between stopping points are of the same length. It is needless to say that these idealized conditions are never all realized conjointly in any practical case. Consequently, the more the conditions of the actual case depart from these idealized conditions, the less the reliance that should be placed upon conclusions and data obtained by methods involving the assumptions aforesaid. It is, unfortunately, not always easy to determine the point at which the simplified method should no longer be trusted in dealing with a practical case. The assumptions made usually lead to incorrect instantaneous speed values at certain points of the acceleration curve, and these errors tend to vitiate the subsidiary curves derived from the speed curves, such as, for instance, the power input curve, whose ordinate values depend upon the speed values. These errors in the power input curve and in the energy consumption calculated therefrom, are likely to affect the motor equipment and the generating station equipment provided for a given service, since the calculations and conclusions regarding them are based upon these subsidiary curves. A relatively small discrepancy between the idealized and the actual conditions may lead to radically different conclusions and results in

these respects, thereby influencing greatly the total cost of equipment, and re-acting seriously upon the capital investment, and the fixed charges involved in the project. Such cases have actually happened.

The " second way " or the use of the speed-time curve as a " method of precision " in concrete practical cases, while a trifle more troublesome, will, in the majority of cases, undoubtedly prove more satisfactory, and less expensive in the end. The truth is, that the practising engineer is very seldom called upon to deal with abstract or general cases. It might be said that every individual case becomes a specific, concrete case, very soon after the engineer begins the process of analyzing and studying it.

The object of this paper is to facilitate the use of speed-time curves as a " method of precision " by contributing certain notes of theoretical and practical observations bearing upon its analysis, or the study of its characteristics, and upon its synthesis, or the principles involved in plotting it.

Technical Definitions.—The generic term " speed-time curve " as used in this paper, is understood to denote any curve showing the velocity of a car or train at successive intervals of time. Figs. 1, 2 and 3 show three different kinds of speed-time curves. In plotting these curves, the horizontal distances or abscissæ are generally used to represent time values (in seconds), and the vertical distances (ordinates), are used to represent speeds (usually measured in miles per hour in this country, and in kilometres per hour wherever the metric system is used).

The curve, in each case, not only shows the speed attained at any given interval of time, but it also shows the variations in speed occurring at various intervals of time. The slope of the curve at any time point is an indication and a measure of the time-rate of change of speed at the corresponding instant of time; and it shows whether the speed is constant, or increasing, or decreasing.

A horizontal speed-line indicates constant or uniform speed. An upward slope in the speed-line indicates increasing speed, or *acceleration*; a downward slope indicates decreasing speed or *retardation*. These characteristics serve to distinguish the different kinds of speed-time curves.

The term " acceleration curve " is usually restricted to curves, or portions of a curve, in which the speed is increasing, or, at least, remaining constant or nearly constant. Such curves corres-

pond to the portions of time during which power is being applied to the train so as to increase the speed or to keep it constant (Fig. 1).

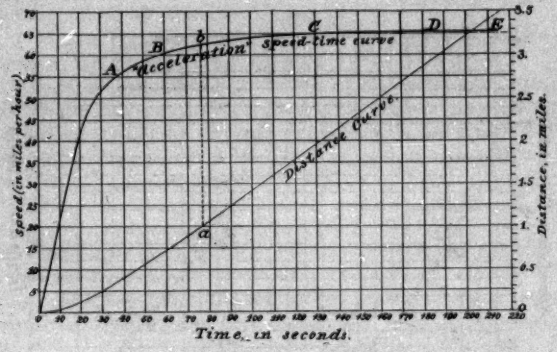


FIG. 1.—Typical Acceleration Curve.

The " retardation curves " are of two kinds, corresponding to different rates of retardation.

The term " coasting curve " or " drifting curve " is used to designate speed-time curves, or portions thereof, corresponding

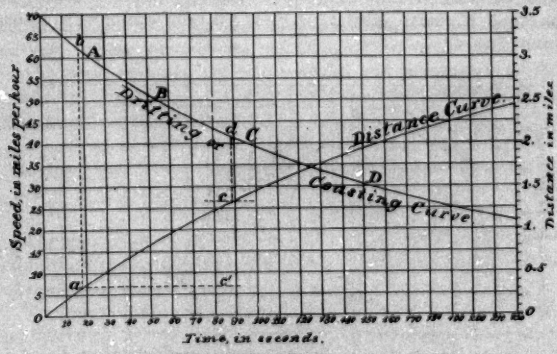


FIG. 2.—Typical Drifting or Coasting Curve.

to intervals of time when the car or train is moving by its own momentum only, and when the rate of retardation is relatively small (Fig. 2).

The term " braking curve " is applied to speed-time curves, or portions thereof, corresponding to intervals of time when the speed is being purposely reduced by means of brakes, and when the decline or decrease in velocity is relatively rapid (Fig. 3).

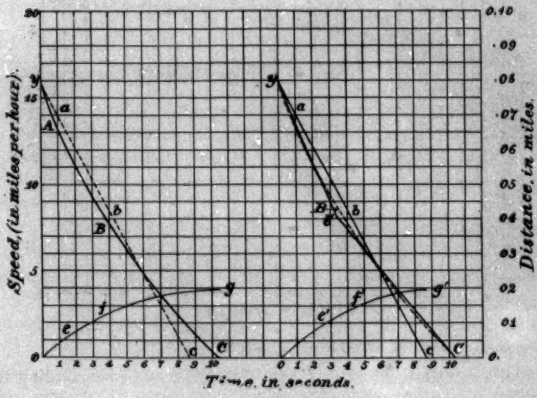


FIG. 3.—Braking Curves.

The term " run curve " is often used to denote a speed-time curve showing all the changes in the speed of a car or train from the time it starts until it stops at the next station or stopping-point (Fig. 4).

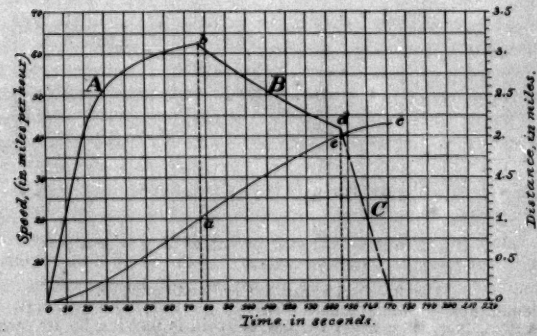


FIG. 4.—Typical " Run Curve."

The first portion of every " run " curve, or the portion during which the train is gaining speed, is an " acceleration " curve. The " run " curve usually, but not always, contains a portion which is a coasting or drifting curve, and it also generally contains a portion which is a braking curve.

The terms " velocity " and " speed " are used as synonymous terms in this paper.

Analytical Definitions.—A certain knowledge of the physical nature and mathematical properties of the various time-function curves mentioned in the previous section is essential for the proper, intelligent use of these curves, and is presumed to be possessed by those who make practical use of them. The precise definitions of these various curves, and the analysis of their properties, involve the analytical study of motion, more especially rectilinear motion. For the convenience and benefit of those who may wish to refresh their memories, or who may wish to go more deeply into the subject (no general treatment of the subject having as yet been published), a brief summarized analytical study of time-function curves, more especially the distance-time and speed-time curves, is given separately at the end of this paper, in Appendix A.

The derivation of the fundamental formulæ relating to train acceleration, constituting the extension of this analytical study, is given in Appendix B.

Appendix C and Appendix D contain the derivation of certain formulæ which are of use and convenience in plotting the " run " curves. These formulæ are not generally known. It is hoped, in this way, to make the paper useful and interesting to those " who wish to know " as well as to those who " already know," the ground-work of the subject.

Appendix E discusses the adaptation of the formulæ to " metric" speed-time curves.

I.—Analysis of Train Motion.

The motion of a car or train under actual or assumed service conditions constitutes an aggregation of different forms or phases of motion.

The " run curve," which graphically depicts the train motion, is, therefore, a " resultant " curve. The analysis of the motion involves the separate determination and segregation of the elementary or fundamental forms of motion, which constitute the components of which the resultant motion is made up.

A glance at a run curve shows three distinct characteristic kinds of lines, which correspond to distinctive phases or kinds of motion, namely, the motions characteristic of acceleration, coasting (or drifting), and braking, respectively.

In Fig. 4 the curve *O b d* is a " run " curve of the simplest character. The first portion (*A*) is a simple acceleration curve. The second portion (*B*), is a drifting or coasting curve, and the final portion (*C*) is a braking curve. The acceleration portion (*A*), is the same as the corresponding portion of the acceleration curve in Fig. 1, from which it was taken. The vertical dotted line (*a* - *b*), indicates the point at which the acceleration line was cut off. In like manner, the drifting curve portion of the run curve in Fig. 4, was taken from Fig. 2, between the points corresponding to the same letters (*b*-*d*). The vertical dotted lines, (*a*-*b*, *c*-*d*) indicate the points at which this curve was cut off. The braking portion (*C*) of the curve in Fig. 4 was calculated.

This particular run curve corresponds to a case in which the power is applied to the car only once, or during the early portion of the run. In actual practice, however, it is often found necessary to allow, or to purposely cause, the speed to diminish, and to subsequently cause it to increase again, at intermediate points of the run. In such case, the run curve will show "notches" or "humps." (Fig. 13.) These notches or humps are almost always due to the occurrence of track curves having a relatively high degree of curvature at points intermediate between stopping points. These curves impose a limit on the speed which it is safe to maintain at such points of the line. When such curves occur at or near the stations, they have less influence on the form of the run curve, because the speeds are lower, owing to the starting and stopping of trains. In such cases they do not cause humps or notches in the run curve, although they do affect the " angle " of the acceleration or of the retardation (braking) curve. The notch or hump in the run curve indicates the fact that acceleration again takes place after the speed has been reduced to the proper or desired limit. This acceleration is followed by drifting and braking, and, in some cases, the run curve may contain several such notches, each of which, as will be readily understood, corresponds to what might be called an " acceleration cycle."

Acceleration.—Each acceleration cycle of a service run, corresponds to the time during which energy from some source is applied to the car or train, so as to cause the speed to increase.

(The physical and mathematical characteristics of acceleration are discussed, summarily, in Appendix A and in Appendix B.)

The energy imparted to a train during an acceleration cycle is absorbed and disposed of by the train in two ways: First.—A portion of it is immediately converted into heat, which represents the energy required and expended in overcoming the various frictional resistances making up what is called "train resistance." Second.—A portion is *stored* as mechanical energy in the "mass" of the train. This stored energy is the energy required either (*a*) to produce acceleration, in which case it is stored as kinetic energy, or (*b*) to lift the train on an "upgrade," in which case it is stored as potential energy. The two forms of stored energy often occur simultaneously. When accelerating on a "down" grade, the stored energy at any instant would, evidently, be equal to the difference between these two kinds of energy at that instant.

The energy concerned in acceleration may be classified under three general heads, namely:

1. The energy required for overcoming the actual mechanical resistance to the motion of the car.

This energy is immediately dissipated as heat.

2. The energy required to overcome grades.

This energy is stored as potential energy.

3. The energy required to overcome the inertia of the car and give it momentum.

This energy is stored as kinetic energy.

The third form of energy, namely, kinetic energy, is the only form usually recognized as being concerned in producing and entering into acceleration. It can be shown, however, that in any case in which acceleration occurs, all other forces than that of kinetic energy may also be estimated in terms of an acceleration, which may be termed "equivalent" acceleration. This has been done in Appenidx B, in equations (24) to (29), by means of which an important theorem is deduced, to the effect that the total acceleration in a moving mass is the algebraical sum of the individual accelerations corresponding to each of the forces acting to produce or prevent the motion of the body. This theorem is doubtless well known in kinematics, although its application to the speed-time curve appears to be new. It is one of those principles which, though not at first readily apparent and somewhat difficult to work out, prove to be really very simple to understand and to apply. According to this theorem, the second form of energy, or the energy required to overcome grades, may be estimated in terms of equiva-

lent acceleration. It is known, as a matter of fact, that the potential energy, or energy of position, in a car which is on a " down " grade, can produce the same acceleration that could be produced by an equivalent tractive effort in pounds per ton, applied to the car in any other way. Conversely, the motion of the car in the contrary direction would produce a contrary effect, or a reduction of acceleration, which could be expressed in terms of equivalent *loss* of acceleration.

Energy of the first kind cannot, strictly speaking, be said to be capable of producing an acceleration. It may, nevertheless, be expressed in terms of " equivalent " acceleration, since, as in the case of a car going up grade, it may be considered as equivalent to a force occasioning a *loss* of acceleration.

In the same manner and by analogy, we might consider the kinetic energy absorbed in pure acceleration as an energy required to overcome an apparent increase in the train resistance due to the inertia of the train, and in like manner, the energy required to overcome grades might be also ascribed to an apparent increase in the train resistance. From this standpoint, the three forms of energy may be considered as having the same kinemetical character. The energy corresponding to an actual resistance represents energy necessarily lost, or which is not recoverable, while the energy corresponding to a " spurious " resistance (analogous to "reactance" in electro-kinetics), represents energy which is not primarily or necessarily lost, but which is really stored, and which is recoverable, wholly in theory, and partially in practice. The former is analogous to the electrical energy dissipated by an " ohmic " resistance, and the latter to the " wattless " energy absorbed provisionally by a "reactance,"—the analogy being so obvious as to require no further explanation.

An acceleration curve is, as pointed out in Appendix A, a speed-time curve, or velocity curve, having a *positive* differential coefficient. This differential coefficient, as shown in Appendix B, in equation (28), is equal to the algebraical sum of the differential coefficients corresponding to the various forces concerned and active in producing the acceleration.

Using the letter " k " with suitable affixes, to designate the individual coefficients corresponding to the individual forces concerned in each case, and using the letter A' to designate the resultant acceleration, we have, from equations (28) and (29) in Appendix B,

$$\frac{dv}{dt} = k \pm k' \pm k'' \pm \text{etc.} = A' \qquad (I)$$

Some of these individual coefficients may be positive, while others may be negative, but the algebraical sum, according to the above definition of an acceleration curve, must be a positive number.

When weights (W) are expressed in tons of 2,000 lbs., and when p = the "equivalent" gross tractive effort or pull corresponding to each of the individual forces concerned in the resultant motion, we have, by analogy to equation (21a) in Appendix B,

$$k = \frac{dv}{dt} = .01098\,\frac{p}{W} \qquad (II)$$

and, reconstructing equation (I) accordingly, we have

$$A' = .01098\,\frac{p}{W} \pm .01098\,\frac{p'}{W} \pm .01098\,\frac{p''}{W} \pm \text{etc.}$$

of which the simplest form is

$$A' = \frac{.01098}{W}(p \pm p' \pm p'' \pm p''' \pm \text{etc.}) \qquad (III)$$

The factor $\frac{.01098}{W}$ is sometimes written $\frac{1}{91.1\,W}$.

When each term "p" is taken in lbs. per ton, the term "W" disappears, and we then have

$$A' = .01098\,(p \pm p' \pm p'' \pm p''' \pm \text{etc.}) \qquad (IV)$$

We must now determine the number and character of the force factors ("p"), by reference to which the resultant acceleration is to be expressed.

The force of the "equivalent" acceleration corresponding to train resistance could be expressed by a single symbol, but it is more convenient to express it by means of two separate symbols, one of which (f), shall correspond to, and shall include, all the factors of train resistance except the increase of resistance due to curvature, which latter may advantageously be considered separately, in which case its equivalent force may be expressed by the symbol "c." The force corresponding to grades may be expressed by the symbol "G." The force corresponding to kinetic energy may be expressed by the symbol "I." In this

case, however, the effect is complicated by the fact that in a moving train there is inertia of two kinds, namely, linear inertia or the inertia due to the entire mass of the car moving in a straight line, and rotational inertia, or the inertia due to the rotating parts of wheels, gears and motors, It is possible, however, to express the rotational inertia in terms of linear inertia. This fact was alluded to in the paper read before this INSTITUTE by Mr. N. W. Storer, in which it is stated that the rotational inertia has the same effect in increasing the total inertia, as if the mass of the car were increased by a certain percentage. This percentage varies in different cases, but Mr. Storer recommends that it be taken at about 10%. We may, therefore, use the same term to designate the effect of linear inertia or rotational inertia, if this term includes the proper correction for rotational inertia. It is just as simple, and it may be sometimes convenient to use a separate symbol ("i") for the rotational inertia.

These several symbols express the forces which react upon and modify the propelling force applied to the car. The forces in each case are understood to be measured in pounds of pull per ton of train weight, this being the basis assumed in the fundamental equation (21a) in Appendix B. The propelling force of the motor may be expressed in terms of an equivalent gross tractive effort (P), (also measured in pounds per ton).[1] In the case of a series electric motor, this gross tractive effort depends upon the amount of current passing through the motor, and also upon the gearing ratio of the motor. The amount of current itself passing through the motor is, as is well known, a function of the speed; consequently the gross tractive effort of the motor is, itself, a function of the speed of the car.

Tabulating these symbols, we have

W = Weight of car or train (in tons of 2,000 pounds).

T = The total or gross traction (due to the current) per motor, (in lbs. or kilos).

$P = T \div W$ = Gross traction in pounds *per ton*.

f = Force expended in overcoming the friction of all kinds, (including axle friction, air and wind resistance, etc., but not including curve resistance), in pounds per ton.

c = The force expended in overcoming the additional resistance due to track curvature.

G = The equivalent traction due to grades. (This factor

1 When using the metric system the force would be expressed in kilograms per metric ton. See Appendix E.

will have + sign on *down* grades, and − sign on *up* grades).

I = The force expended in overcoming linear inertia.

i = The force expended in overcoming rotational inertia.

p = Resultant force expended in acceleration. $(=I+i)$.

The factors. f, c, G, I, i, are all expressed in pounds per ton of train weight.

From this it is seen that we have to consider a total of six (6) terms of the type "p."

The term "f" expressing train friction varies, as is well known, as a function of the train speed, same as the gross traction.

The term "c" varies with the degree of curvature. This term only occurs in those portions of speed-time curves which correspond to points on the run at which there are track curves. It is usual to assume this resistance as equivalent to from 0.7 to 0.9 pound per ton per degree of curvature. Thus, assuming a coefficient of 0.8, a track curvature of 5 degrees would increase the train resistance by an amount equal to 4 pounds per ton.

The term "G" depends upon the percentage of grade, and is constant for each percentage. For example, a grade of 1%, which means a rise of one foot per hundred, would be equivalent to lifting the train weight (W) one-hundredth of the distance, or lifting one-hundredth of the weight the entire distance. Each ton of 2,000 pounds would, therefore, occasion an apparent increase in train resistance equivalent to 20 pounds per ton.

From the above, it is seen that the value of G in any particular case will be

$$G = 20\,q$$

in which q expresses the percentage of grade.

The terms "I" and "i" together represent, as will be understood from the preceding discussion, the net force—or the force which is expended in acceleration, (and stored as kinetic energy).

We may retain the term "p" to express this net force, so that

$$p = I+i$$

If we substitute the above terms for the terms p', p'', etc., in equation (IV) we have

$$A' = .01098\,(P - f - c \pm G) = .01098\,p \qquad (V)$$

The signs of "f" and "c" will always be minus.

The sign of "G" will be + when the car is on a *down* grade, and it will be − when the car is on an *up* grade.

We thus see from equation (V) that the differential coefficient of an acceleration curve may be simplified in expression until it is equivalent to the algebraical sum of various factors representing "real" or "spurious" train resistances, multiplied by a constant. The algebraical sum referred to is nothing more than the net pull, since, if we equate the last two terms of the equation, the coefficient .01098 disappears, and we have, simply,

$$p = P - f - c \pm G \qquad (VI)$$

Each term, taken separately with the constant, indicates the equivalent acceleration corresponding to said term, expressed in miles per hour per second. Thus, in the case of the gross traction, (P) the quantity .01098 P would mean the acceleration in miles per hour per second, which would be obtained if it were not for the modifying factors, f, c and G.

Retardation.—In the second portion of each cycle of train motion, there is a stage of motion during which the car moves without extraneous power being employed, it being impelled by the kinetic energy previously stored in it during acceleration. The car is then said to be "drifting" or "coasting." The coasting or drifting motion would continue, with the speed in the meantime gradually diminishing, until the kinetic energy stored in the car or train has been entirely dissipated in overcoming the train resistances, when it will stop. When the rate of dissipation of the kinetic energy is purposely increased by friction shoes bearing against the car wheels, the retardation is more rapid, and the car is then said to be "braking." A braking curve is, therefore, a retardation curve showing a high rate of retardation.

A retardation curve may be defined as a velocity curve having a negative differential coefficient. (See Appendix A, last paragraph.)

In a coasting curve, the coefficient is relatively small; in a braking curve, it is high.

The same equations which apply to acceleration will apply to retardation. In this case, however, since power is no longer being applied to the car, the quantity "P" will be zero, and will, consequently, disappear from the equation. The only terms remaining will be f, c and G, so that the equation will now become

$$-A' = .01098\,(-f - c \pm G) = -.01098\,p \qquad (VII)$$

If there happen to be no curves or grades, the equation will be, simply:

$$-A' = -.01098\, f = -.01098\, p \qquad (VIII)$$

whence we have

$$-f = -p$$

or the force (p) due to the kinetic energy is exactly equal to the force required to overcome the train resistance (f). The minus sign indicates that the acceleration is negative, or that its rate is a decreasing one. The energy producing acceleration comes, of course, from the kinetic energy stored in the car. The rate of decrease of the speed will be exactly such as to produce the force p ($= f$), and no more. This is in accordance with equation (22) in Appendix B. It seems strange until we stop to consider the two following circumstances: first, that the only way in which the energy of the car can be dissipated, when braking, does not occur, is by means of the friction due to train resistance; second, if the speed variation could, in any way, become greater than that which corresponds to and develops a force equal to that of the train resistance (in accordance with equation 22), there would be a surplus of force, and this surplus could only be expended in producing acceleration, or in the re-acceleration of the car. It is evident, therefore, that the rate of retardation of the car must, of necessity, be exactly such as, and can be no more than, will suffice to cause the kinetic energy stored in the car to be dissipated at precisely the rate required to overcome the train resistance, and also the effect of track curve resistances, and of up-grades, if there be any. It is worth while to note that the case would be different if the car were running on a down grade, for, in this case, G is not equal to zero, but has a positive value, and consequently, represents a force which is, of itself, capable of producing acceleration. Under those circumstances, we should, therefore expect, and we find in practice, that a higher rate of acceleration is produced.

When braking the car, there is, as already stated, an additional retarding force. This retarding force, which may be designated by the symbol "B" enters in the fundamental equation with the negative sign, so that we have:

$$-A' = -.01098\,(-B - f - c \pm G) \qquad (IX)$$

In practice, it is usual to speak of a braking force of so many pounds per ton. For high-speed work, the value generally taken is $B = 150$. As pointed out in Section II, in discussing

the subject of plotting braking curves, it is usual, for the purpose of simplification, to assume that this figure (150), also represents and includes the values of f and c, so that the equation, as used in practice, would generally be simplified to the following form:

$$-A' = -.01098\ (150 \pm G) = 1.647 \pm (.01098\ G) \qquad (X)$$

In the coasting curve, as well as in the braking curve, the effect of a down-grade, which makes the sign of "G" a plus sign, will be, evidently, to decrease the rate of retardation, while the effect of an up-grade, making the sign of "G" minus, will be to increase the rate of retardation.

The equation shows that the slope of the braking curve will depend, not only upon the value of the braking friction (B), but also upon the train resistance, also the track curvature and percentage of grade, if any.

The term "B" is generally assumed constant, and independent of the speed. This is not exactly true, however. The true braking curve (y, A, B, C in Fig. 3), is, like the drifting curve, more or less convex to the axis of "x," especially in the middle portion. The straight line (in Fig. 3) (y, a, b, c), indicates the (constant) rate of retardation that would be required to bring the car to a stop within the same *distance*. It will be seen that with a constant rate of retardation, the car would come to a stop a little sooner than is actually the case in practice. The data available from actual tests are still so meagre, and the analysis of them is so incomplete, that engineers are still obliged, however, to assume a constant rate of retardation in dealing with the braking curve. This point is again referred to in Section II.

In the foregoing equations, the individual acceleration coefficients which make up the resultant coefficients are represented by means of various terms indicating a force or pull in pounds per ton, multiplied by a constant. This has been done because of the established practice among engineers, of estimating the accelerating force in *pounds per ton*. The writer believes that a more satisfactory way would be to estimate acceleration in miles per hour per second, using equations of the type shown in equation (I) rather than those of the type shown in equation (IV.) The advantage of equation (I) is the fact that it gives the resultant acceleration in terms of the individual accelerations expressed in *miles per hour per second*. Translated into words, this equation means that the total or resultant acceleration

is obtained by taking the difference between all the positive acceleration coefficients and all the negative acceleration coefficients The transition from one type to the other has been clearly indicated, and it is not necessary, therefore, to repeat the equations in the modified form. In plotting the curves by the method which will now be described, the values used are those obtained by equations corresponding to equations (*V*), (*VII*) and (*IX*), but patterned after equation (*I*).

II.

The Plotting of Speed-Time Curves.

The information and knowledge obtained in the preceding investigation of the nature and character of the three kinds of fundamental speed-time curves, namely, the acceleration curve, coasting curve and brake curve, is of much practical utility and convenience in the plotting of these curves, and also in the plotting of run curves, which, as we have already seen, are in reality made up by joining together various portions of acceleration, drifting and braking curves.

In this case we must, in a measure, reverse the process followed in the analysis of train motion, for, instead of separating the curve into its components, we must assemble these components synthetically, so as to produce the curve.

Preliminary Considerations.—There are certain considerations which enter into the discussion of every specific problem in train motion. These include many things such as the character and location of the railway lines to be operated, the nature, character and other characteristics and conditions of the train service required, etc., etc. These things react upon and determine the schedule speed, headway and other service conditions, which, in turn, together with the total weight of a loaded train unit, determine the character and capacity of motor equipment required per train unit. A complete analysis of all these characteristics and conditions is beyond the scope of this paper. The preliminary calculations, by means of which the first approximation is made in regard to the number and capacity of motors per train equipment, are also beyond the scope of this paper.

The purpose of this section of the paper will be fulfilled if we assume that the motor equipment has already been decided upon, since one of the principal practical applications of the speed-time

curves, more especially the service run curve, is to test or gauge the qualities and fitness of a specific equipment, by furnishing information as to whether the proposed equipment is capable of doing the service required or wanted under the actual or assumed service conditions.

The plotting of the three fundamental speed-time curves will first be discussed, after which we will be better prepared to understand the process of plotting the run curve.

Acceleration Curves.—The acceleration curve of a car, being the criterion of the performance of this car and of its motor equipment, must be constructed by reference to the fundamental data relating to the performance of the particular electric motors used in the said equipment. These data are carefully determined by the motor manufacturers, by means of more or less comprehensive and elaborate special tests made for that purpose, and they are shown graphically on certain curves known as "motor characteristic curves" (Fig. 5), which usually give the relation between the various values of current (amperes) sent through the motor, and three different quantities namely, the tractive effort or horizontal pull (pounds) exerted by the motor, the speed attained (m.p.h.), and the efficiency obtained, corresponding to the current values. The currents (in amperes) are usually represented in these diagrams by distances measured horizontally, while the other three quantities are represented by distances measured vertically, each according to its own appropriate scale. The tests of which the curves are the graphical summary and representation, are based in each case upon a particular gear ratio, which is noted on the curve sheet. These curves are sometimes made for various gear ratios, but usually are made only for one or two particular gear ratios. By means of these curves, the curves corresponding to other ratios can be easily obtained.

These curves are usually based upon tests made at a standard voltage of 500 to 550 volts. If the voltage to be used in the case under consideration is greater or less than the standard voltage, a correction will be required in the speed values. The speed in a series motor is, as is well known, practically proportional to the potential difference at its terminals. Hence, an increase in the voltage will increase the train speed in proportion. If, for instance, in the actual case, a mean voltage of 600 volts were assumed, the corrected speed curve (B, in Fig. 5), would be one having ordinate values 20% greater at every point. The curve of tractive efforts (A. B.) would remain un-

changed so long as the gearing ratio remained the same. A change in the gearing ratio has the effect of modifying both the tractive effort and the speed. If the gearing ratio is made such as to cause the train to run faster, that is to say, if the number of teeth in the driving or motor pinion is increased, while the number of teeth in the driven wheel or gear on the car axle is correspondingly reduced, the result will be to raise the

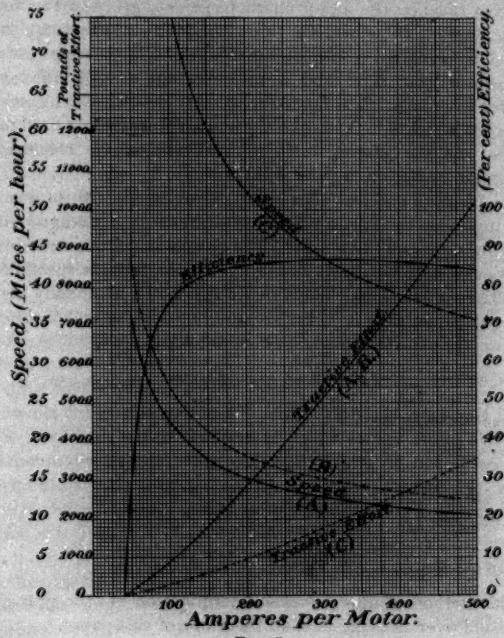


FIG. 5.

speed, while lowering the tractive effort; and vice versa. The corrected curves corresponding to each particular gear ratio, may be drawn and a new set of curves can be made for each change. This is not absolutely necessary, however, since the corrected values, both for speed and tractive effort, may be obtained direct from the original curves, by multiplying the values therein given by a suitable correcting factor or coefficient, as is

well known. The speed correcting factor may include both the change in voltage and the change in gear ratio; or we may correct either of those two things separately. When a change is made in the gear ratio, a correcting factor will also be required for the tractive effort—this factor being equal to the reciprocal of the factor determining the change in speed, due to change in gear ratio. An illustration of the effect of change in voltage and in gear ratio on the motor characteristics is given in Fig. 5. In this diagram the speed curve drawn with solid line (A), is the curve showing the results obtained in the original shop test with a certain gear ratio and a mean voltage of 500 volts at the motor terminals. The dotted speed curve (B) shows the increase in speed which would result if the mean voltage were raised to 600 volts. As the gearing ratio remains unchanged, the tractive effort curve shown by the solid line, (A-B), would remain the same for both speeds. The speed curve drawn with broken line (C) indicates the speed values resulting from a change both in gearing ratio and in voltage. The change in gearing ratio in this particular case was such as to increase the relative speed of the car 2.87 times. The change in voltage being, as already stated, such as to increase it in the ratio of 600 to 500, or 1.2 times, it follows that the total increase of speed was

$$1.2 \times 2.88 = 3.46 \text{ times.}$$

In this case, the dotted line of tractive efforts (C) shows the tractive effort values which correspond to the speed curve (C). The coefficient, by which the values of tractive effort corresponding to the curve A must be multiplied, is, as already stated, equal to the reciprocal of the change in gearing ratio,

$$\frac{1}{2.88} = 0.347$$

The method of approximate determination of the gear ratio is passed over as being beyond the scope of this paper.

The various correcting factors, if any, having been determined and applied, in each particular case, substantially in the manner just indicated, the corrected values of tractive effort and speed corresponding to the various current values will now be known; and these values may be plotted in curves analogous to the corrected curves (C) in Fig. 5. Dividing the tractive effort values, which correspond to the various current values, by the total weight of train expressed in tons, we have the gross tractive effort

per ton, which is the quantity " P " used in equation (V). Taking the speed values and the tractive effort values corresponding to the same current values, we may tabulate the tractive effort values as a function of the speed. On referring to equation (V), we see that we still need the values of the terms f, c and G. It is usual to begin by plotting the acceleration curve corresponding to a level and straight track. In such a case, the values of c and G both become zero. The values of the train resistance (f) are usually computed for different speeds, by means of some particular formula. The number of these formulæ is legion, but a completely satisfactory and comprehensive one still remains to be found. The latest and perhaps the most authoritative information on this subject will be found in some articles on " Train Resistance " in the *Street Railway Journal* for May and June, 1902.

By means of the two sets of values of P and f, and using the formula given in equation (V), the acceleration coefficients A', corresponding to various definite values of these quantities, and, therefore, to certain definite speeds, may be computed and tabulated. We then have two things, namely, the speed value and the acceleration coefficient corresponding to said speed. In the first method used for plotting speed-time curves, this is all the information that was required. The process of plotting consisted in drawing ordinates equal to the speed value, and drawing tangents to these ordinates equal to the acceleration coefficient—then displacing the ordinate to the right or left, until the tangent line met the tangent line corresponding to the ordinate of the previous speed point.

Reference to Fig. 6 will clearly show the general nature of this method. The process of plotting consisted in drawing ordinates such as y, y', y'', equal to various speed values, and then drawing at the upper end (A, B', C') of each of these ordinates, a tangent line whose angularity is proportional to the corresponding acceleration coefficient for each of these ordinates. The ordinates are then to be displaced sidewise (to the left, in this case), until the tangent line of any ordinate meets or crosses the tangent line corresponding to the ordinate of the previous speed point—that is to say, of the ordinate immediately to the left of it. The proper meeting points (m, n) between the tangent lines are to be determined by the eye, being located usually about halfway between the two corresponding ordinate points. The process might be illustrated by means of a file of soldiers of unequal height, with

outstretched arms, and moving closer together until their hands touch. If the proper place of the tangent to the ordinate y in Fig. 6 is at the point A on the curve $OABC$, then the tangent lines B' and C' would find their proper places when the ordinates y' and y'' have moved to the left as far as the points B and C respectively. The curve $OABC$ osculating these tangent lines, as shown in the figure, would be the curve required. This method has serious drawbacks. In the first place, it is not easy to determine the proper points, m and n, at which the tangent lines should meet. The difficulty of accurately drawing the tangent line itself is already very great, without the difficulty of determining by the eye the distance at which the next ordinate should be placed. If, for instance, in Fig. 6 the tangent lines were made to meet at the points m' and n', corresponding to the mean ordinate, or half of the speed increment, instead of meeting at the exact points, m and n, the result would be to displace each

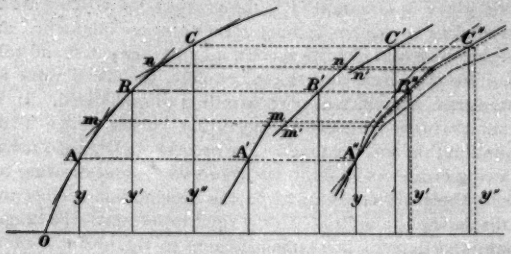


FIG. 6.

ordinate, as clearly shown at the right end of the diagram, where the solid tangent lines passing through the points A'' B'' and C'' represent the tangent lines in the same relative locations as the tangents at the corresponding points in the curve $OABC$, while the dotted lines represent the effect of changing the meeting point from the points m, n, to the halfway points, m' and n' respectively. The diagram also shows the effect of an error in the angle of the tangent line. This error is usually constant, being due to the particular method of drawing and the protracting instruments used. It is, therefore, apt to be a cumulative error. As clearly indicated by the broken lines, starting from the initial ordinate at the point A'', the diagram shows the increase in divergence resulting from a constant error in angularity, the effect being to make the curve too high when the angle is too large, and too low when the angle is too small. The errors due to the two

causes might be cumulative, or they might tend to partially compensate each other. In the diagram it is clearly seen that, under the conditions shown, the errors would tend to compensate if the error in the angle of the tangent was such as to make this angle greater than it actually is, while they would be cumulative in the contrary case. The method is totally unscientific and unsatisfactory, notwithstanding the fact that it is still used. There is really no telling what the percentage of error may be. It is all conjecture and guess-work.

No method of curve plotting can be entirely satisfactory without some means of pre-determining *both* coördinates of each point to be plotted. The method of calculating the time increments, as analyzed in Appendix C, constitutes a great improvement on the method just described. The method is sufficiently described in Appendix C. By means of this method, using equations (*i*) and (*ii*), the time points corresponding to the various speed points, may be determined with any degree of accuracy desired. The conditions influencing the accuracy, and the error to be expected, in any case, are fully discussed in Appendix C. These time values having been tabulated, the curve may be plotted by locating the ordinates on a sheet of paper in the usual way. After obtaining the coordinates for an acceleration curve on a straight and level track, we can, by assuming proper values for G, in equation (V), obtain and tabulate the acceleration coefficients of other acceleration curves corresponding to various grades; and the time values corresponding to the various speed values having been computed and tabulated, these curves may be plotted. Fig. 7 shows a set of nine acceleration curves, including one for a level and straight track, four for up-grades of $\frac{1}{2}\%$, 1%, $1\frac{1}{2}\%$ and 2% respectively, and four for the corresponding down-grades. This method, while more simple and far more accurate than the crude " tangent " method, still admits of improvement.

The method to be described has the advantage of being practically a graphical method, and of being comparatively simple and quick in practical use. Incidentally, it serves many useful purposes, by giving graphically and accurately, in readily intelligible manner, the answer to many questions, the answer to which otherwise necessitates and involves more or less tedious computations and some thought. The method is based upon the theorem given at the end of Appendix B, to which reference has already been made. It requires two charts, which may be

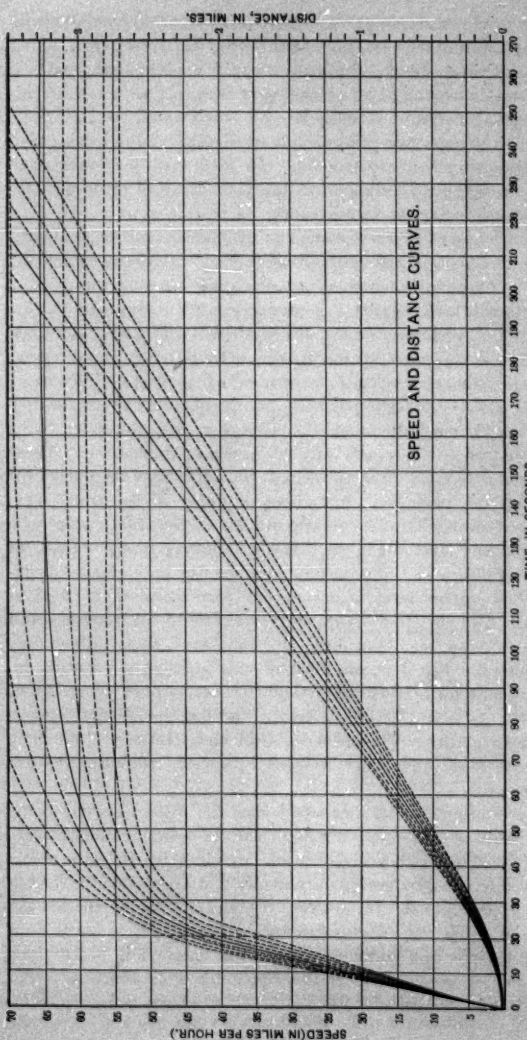


FIG. 7.—Chart of Accelerations.

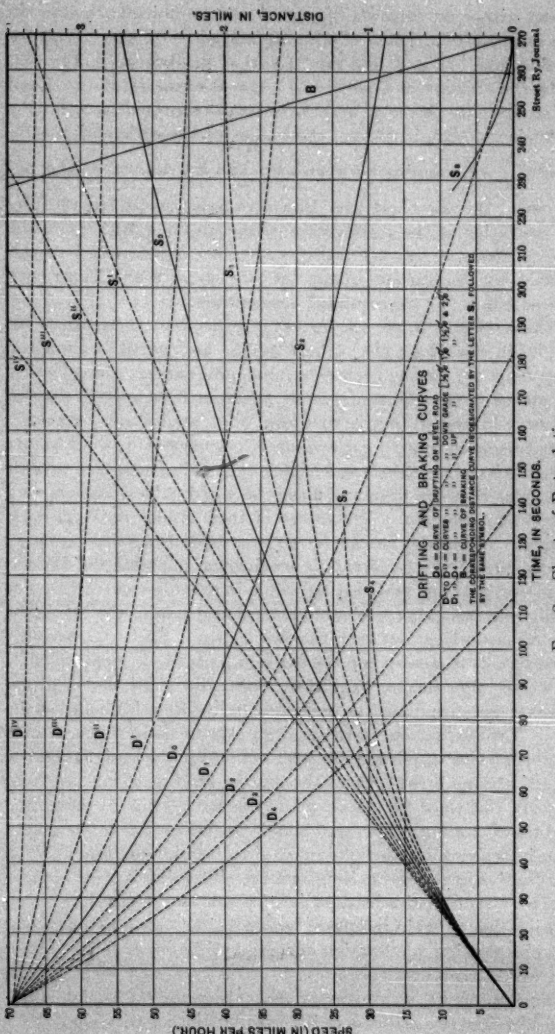

DRIFTING AND BRAKING CURVES
D1 = CURVE OF DRIFTING ON LEVEL ROAD
D2 TO D7 = CURVES " " DOWN GRADE 1.5% TO 7.5% BY 1.5%
B = CURVE OF BRAKING
THE CORRESPONDING DISTANCE CURVE IS DESIGNATED BY THE LETTER S, FOLLOWED BY THE SAME NUMERAL
TIME, IN SECONDS.
SPEED (IN MILES PER HOUR.)
DISTANCE, IN MILES.
Street Ry. Journal

FIG. 8.—Chart of Retardations.

drawn either on separate sheets, or else combined together on the same sheet. These charts, are respectively, the "Chart of Coefficients," (Fig. 9) and the "Chart of Reciprocals" (Fig. 10.)

In the "Chart of Coefficients" the abscissæ represent speed values in miles per hour, and the ordinates represent acceleration coefficients, that is to say, the values of the differential coefficients $\frac{dv}{dt}=k$, ranging between zero and 2.5 miles per hour per second. On this chart are drawn various curves representing the variation of the acceleration coefficient, as a function of the speed. These curves are really curves of "equivalent" acceleration for the various quantities, P, f, G, c, which enter into the equation (V) for resultant acceleration.

The curves Q, R, are the curves of equivalent acceleration for the train resistance (f). These curves are plotted as follows: The value of f having been determined, for various speeds, either by means of some formula, or by reference to tabulated data or to curves obtained from actual tests, the "equivalent" acceleration corresponding to each value is calculated by the formula given in equation $(21a)$; and each acceleration coefficient value is then plotted as an ordinate, using the speed value corresponding thereto as abscissa. The curve is then drawn through these points. In one of the curves (Q), the resistance values (f) used in computing the acceleration coefficients, included the friction of motor bearings and gearing, while in the other curve (R), this additional resistance was excluded. This explains the difference in ordinate values between the two curves. The first curve (Q) corresponds to cases when the car is moving by momentum only, at which times the mechanical resistance due to friction of motor bearing and gears must be overcome by the kinetic energy of the car. The second curve (R) corresponds to cases when motive power is being applied to the car. It is true that this resistance still consumes energy when the motors are furnishing power to the car, but since the curve of tractive effort (Fig. 5) represents the tractive effort which is available for *external work*, it follows that in determining the amount of gross traction per ton, ("P"), the friction of motor bearings and motor gearing is already eliminated. It is for this reason that two curves of equivalent acceleration due to train resistance are required, (Q, R),—one to be used in plotting acceleration curves, and the other to be used in plotting retardation curves.

The curves Q′, R′ are the same as the curves Q, R, but reproduced below the axis of x (with ordinates of negative sign).

PA

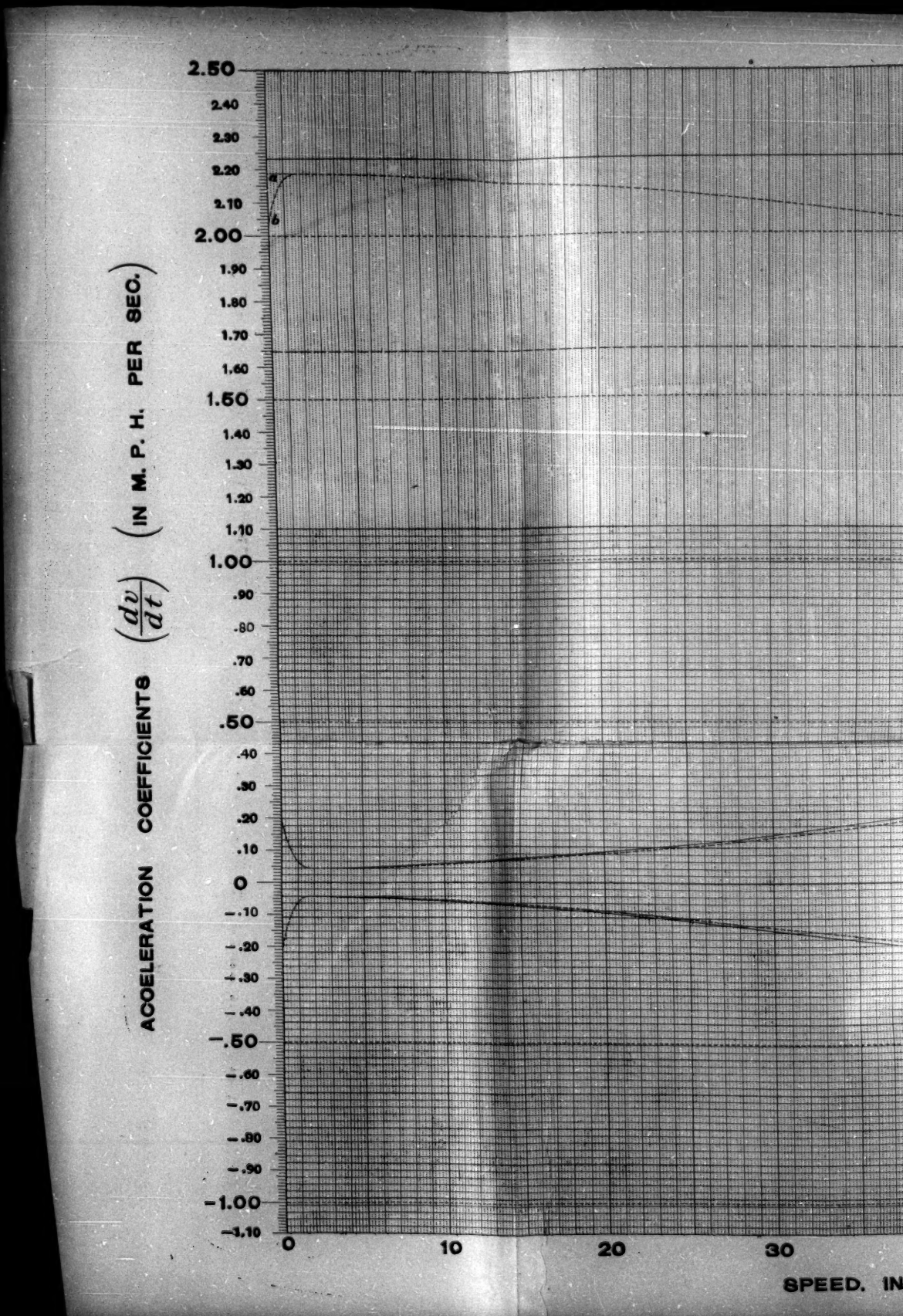

ACCELERATION COEFFICIENTS $\left(\frac{dv}{dt}\right)$ (IN M. P. H. PER SEC.)
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
-.10
-.20
-.30
-.40
-.50
-.60
-.70
-.80
-.90
-1.00
-1.10
0
10
20
30
SPEED. IN

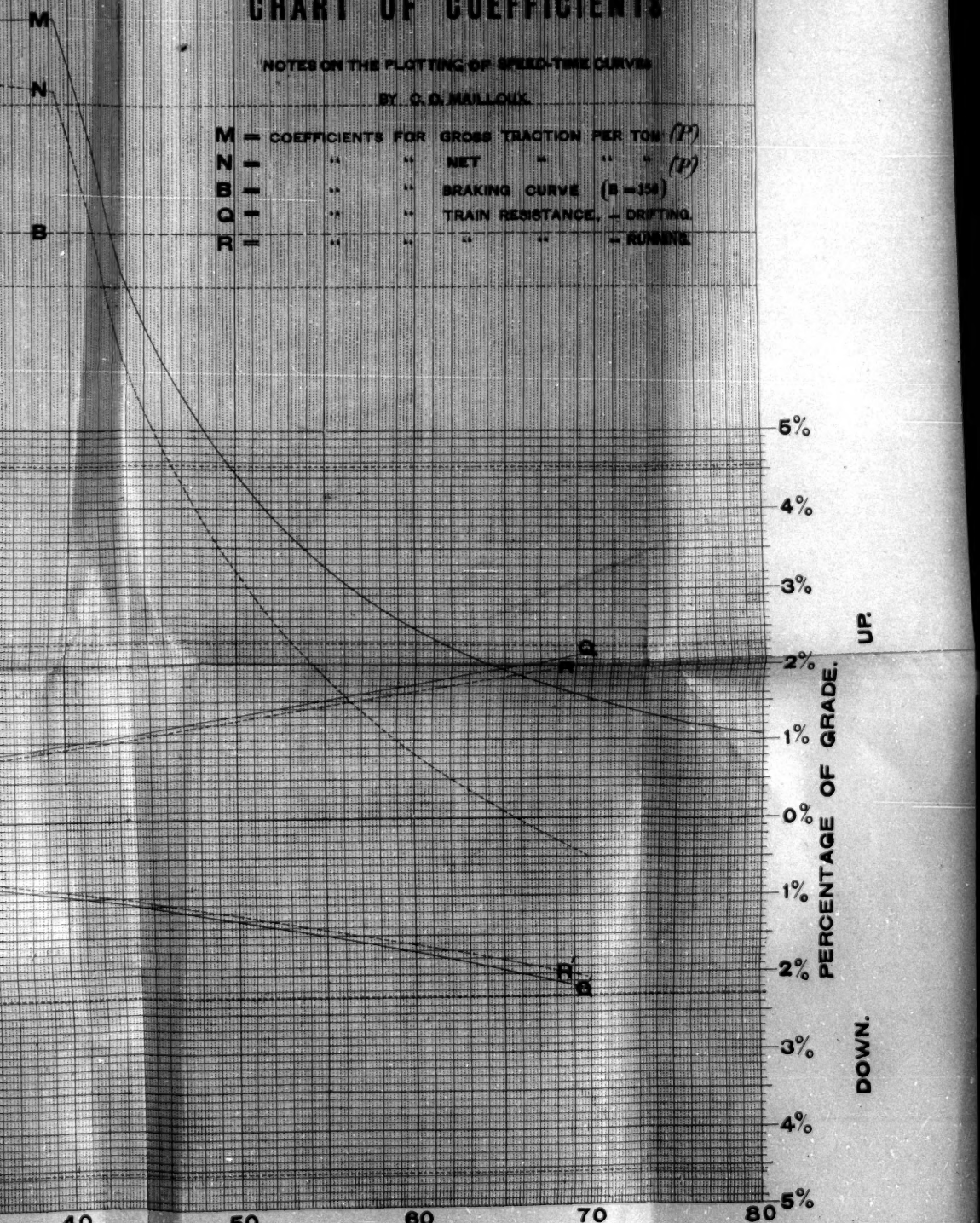
FIG. 9

CHART OF COEFFICIENTS

NOTES ON THE PLOTTING OF SPEED-TIME CURVES

BY C. D. MAILLOUX.

M = COEFFICIENTS FOR GROSS TRACTION PER TON (P)
N = " " NET " " " (P)
B = " " BRAKING CURVE (B = 15R)
Q = " " TRAIN RESISTANCE, — DRIFTING.
R = " " " " — RUNNING.



(The train resistance values for speeds above 1 m.p.h. used in computing the coördinates of the curve R, agree substantially with the values obtainable for the train resistance of a single car by the formula of Mr. W. J. Davis, Jr. (see *Street Railway Journal*, Vol. XIX., May 3, 1902, p. 554). Between 0 m.p.h. and 1 m.p.h. the train resistance values used are such as to make allowance for the increase in train resistance when starting from rest. The curve, as drawn, indicates an initial starting resistance of about 18 lbs., per ton. For further information on this subject see paper on " Train Resistance " by J. A. F. Aspinall, M. I. C. E., read before the Institution of Civil Engineers, Nov. 26, 1901).

The curve M gives the equivalent acceleration values of the *gross traction* (P) of the particular motor equipment, whose time-function curves are to be examined. This curve is prepared substantially in the same manner as the curves Q, R, the values of P being determined by reference to the " corrected " motor characteristic curves, as already stated. The acceleration coefficients corresponding to the gross traction (per ton) obtainable at various speeds, are computed by equation (21*a*), and the values so obtained are plotted on the chart (curve M).

The curve N is what might be called a curve of " net " acceleration coefficients, obtained by subtracting the ordinate values of the train resistance coefficients (curve R) from the corresponding ordinate values of the gross traction coefficients (curve M).

The gravity factor, G, is, as we know, independent of the speed; consequently, the value obtained by equation 21*a*, for any given value of G, corresponding to any definite gradient, is constant at all speeds; the resultant curve will, therefore, be a straight line, parallel with the axis of x. In the chart, these lines have been drawn at the proper calculated ordinate distances corresponding and equivalent to all percentages of grades between 0.1% and 5%. These gradient percentage lines have been repeated below the axis of x, the two sets being thus suitable for up-grades and down-grades.

Since, as already seen, a grade of 1% represents a force of 20 lbs., it follows from equation (V), that the acceleration coefficient due to such a grade would be

$$= .01098 \times 20 = .22 \text{ m.p.h. per sec.}$$

It follows, therefore, that the scale of gradient percentages given at the right-hand end of the chart is such that the vertical distance, corresponding to each 1% of grade, is equal to 0.22

when measured on the scale of coefficients at the left-hand end of the chart.

The quantity c being also constant at all speeds, will also be represented by a straight line. The curves corresponding to this value are not shown on the chart.

The correction for curvature may, however, be made by reference to the gradient percentage lines, the effect of the track curvature being the same as an equivalent "up-grade." Since a 1% grade corresponds to 20 lbs. of tractive effort, the number of degrees of track curvature which is equivalent to a 1% grade will be

$$\frac{20}{b} = N \qquad \text{(XI)}$$

where N = the number of degrees of curvature.
and b = increased train resistance in lbs. per ton per degree of track curvature.

And the "equivalent grade percentage" would be:

$$G = \frac{N\,b}{20} = .05\,N\,b \qquad \text{(XII)}$$

As an illustration, let us assume an up-grade having an actual gradient of 2.672%, and a track curvature of $4° - 30'$ (4.5°), and let b equal 0.9. The equivalent grade due to the curvature would be:

$$\frac{4.5 \times 0.9}{20} = 0.203\%$$

The effect under those conditions, would, therefore, be the same as if the total grade were:

$$= 2.672 + 0.203 = 2.875\%$$

In the case of a down-grade, the effect of course would be equal to the difference between these two values, or

$$-2.672 + 0.203 = -2.469\%$$

This net value which includes the allowance for both gradient and curvature is the value that would be used in plotting the curve by means of the Chart of Coefficients.

When b equals 0.8, we have, from equation (XI)

$$N = \frac{20}{0.8} = 25°$$

In this case the coefficient for each degree of curvature would,

therefore, be 1/25, or 0.04, of the coefficient corresponding to a 1% grade. It follows, therefore, that two of the smaller spaces, each corresponding to a tenth of a 1% of grade, would represent the coefficient for 5° of track curvature.

When b equals some other number, the relation between the two kinds of coefficients is not so simple, for which reason the writer finds it preferable to make all corrections for track curvature by reference to equation (XII).

When there is no track curvature, the algebraical sum of acceleration coefficients includes only three coefficients, namely, those due to the gross traction, the train resistance and the grade. The curve N being already the algebraical sum of the first two, it follows that we have only to take either the *sum* or the *difference* in ordinate values, at any speed point, between the curve N and the horizontal line corresponding to any gradient, in order to obtain the corresponding resultant acceleration. This resultant acceleration coefficient is equal to the SUM of the ordinate values in the case of a DOWN-grade, and to their DIFFERENCE in the case of an UP-grade. Thus, on a down-grade of 1%, the resultant coefficient would be equal to the full vertical distance between the curve N and the " 1% " line *below* the " zero " line (or axis of x), just as if the zero line itself had been displaced downward as far as the " 1% " down-grade line. The effect of an up-grade would be exactly contrary, being the same as if the zero line had been displaced upward to the corresponding up-grade " percentage " line. The point at which the curve N crosses any gradient percentage line corresponding to an up-grade being, of course, the point at which the equivalent acceleration coefficients cancel each other and give a resultant acceleration equal to zero, it follows that this point is at the maximum speed that the particular motor equipment under consideration would give on that grade. If, instead of an up-grade, we examine the point of intersection of the curve N with a down-grade, we find, as is to be expected, that the maximum speed will be considerably higher. The chart may also be used to answer questions such as the following: On what down-grade, at any given speed, would the equivalent acceleration due to gravity be the same as that due to the train resistance? Also, on what grades would this force be sufficient to cause acceleration, and at what rate? The answer to this question is obtained very easily by taking the ordinate of the curve (Q), corresponding to any speed, and comparing it with the ordinate corresponding to any

grade. When the two values are alike, there is no resultant acceleration. If one is greater than the other, there will be acceleration or retardation, according to the case. The chart thus answers at once, and in a very satisfactory manner, all questions in regard to the speed attainable under any desired set or aggregation of conditions. The Chart of Coefficients is, therefore, an instrument for quickly and accurately determining the answer to equations (28) and (*I*) under any kind of conditions, actual or hypothetical.

The train resistance coefficients, when once *properly* determined, will serve for any case. where the *train units* are of the same *kind* and *character*, it being now known that the train resistance values ("f," from which the curve R is derived), vary with the number of cars per train, and it being probable that they also vary according to the form and the size of car. It is evident that several different curves, analogous to the curve R and corresponding to train-units of different kinds, may be all plotted on the same chart of coefficients. The gradient percentage lines on the chart will, for obvious reasons, be the same for all cases whatsoever. Hence, we have only to plot the curve of gross traction coefficients (M) for any other motor, to be at once able to answer all questions about the speed and acceleration obtainable under any and all conditions. It is not well, however, to plot too many curves on the same chart, especially when they run closely together. It is more convenient, less confusing, and therefore preferable, to use a distinct chart for the "traction" curves (M and N), and for the "resistance" curves ("R") corresponding to each kind of train-unit, or for not more than two distinct kinds of train-units.

It is desirable to plot the Chart of Coefficients with a rather large scale of ordinates. The scale of ordinates, in the original Chart of Coefficients, from which Fig.9 was made, is such that 1 m.p.h. per second equals 20 centimetres, so that the acceleration coefficient values may be easily read and plotted to the third decimal place. This accuracy is not so important for the portions of speed-time curves having a high rate of acceleration, but it becomes very important in the case of low accelerations, that is to say, in plotting the relatively flat portions of acceleration and retardation curves. In these portions, the acceleration coefficients have relatively small values, and consequently the percentage of error would be increased, unless these values can be read at least to the second, preferably to the third decimal place.

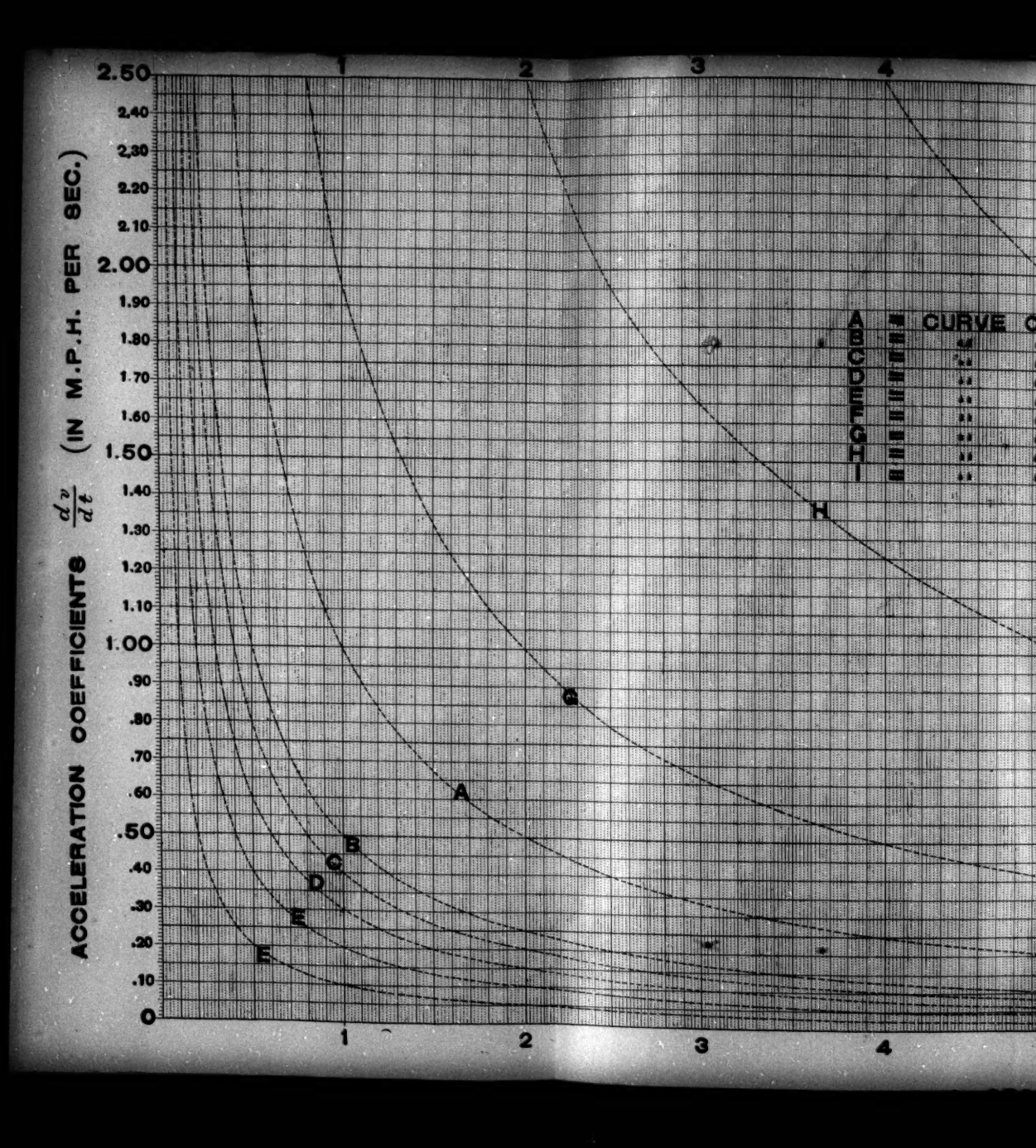

ACCELERATION COEFFICIENTS $\frac{dv}{dt}$ (IN M.P.H. PER SEC.)
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
1
2
3
4
CURVE
A
B
C
D
E
F
G
H
I

FIG. 10.

CHART OF RECIPROCALS.

"NOTES ON THE PLOTTING OF SPEED-TIME CURVES."
BY O. O. MAILLOUX.

OF RECIPROCALS. WITH 0.5 x-y (USED WHEN Δv=0.5 M. P. H.)
" " " 0.4 x-y " " " 0.4 " " "
" " " 0.3 x-y " " " 0.3 " " "
" " " 0.2 x-y " " " 0.2 " " "
" " " 0.1 x-y " " " 0.1 " " "
" " " 2 x-y " " " 2 " " "
" " " 5 x-y " " " 5 " " "
" " " 10 x-y " " " 10 " " "

5 6 7 8 9

2.50 2.40 2.30 2.20 2.10 2.00 1.90 1.80 1.70 1.60 1.50 1.40 1.30 1.20 1.10 1.00 .90 .80 .70 .60 .50 .40 .30 .20 .10 0

The greater ease and facility with which a chart can be used when plotted to a larger scale really simplifies the task of plotting the curves, and probably saves time in the end.

It is obviously desirable that the scale of *ordinates* be precisely the same in both charts, since otherwise it would be necessary to use proportional dividers or equivalent means of compensation for the difference in scales, in transferring the ordinate values from the Chart of Coefficients to the Chart of Reciprocals, in order to get the proper time increment values corresponding thereto. For this reason the two charts should be both made on the same kind of coördinate paper.

The charts shown in Figs. 9 and 10 have been reproduced with a view to making them suitable for practical use. For this reason they have been reproduced in sufficiently large size to permit accuracy in plotting or reading the coefficient values, and great care has been taken in the photo-engraving to have the scale of ordinates exactly the same in both charts

The Chart of Reciprocals (Fig. 10), serves for determining quickly the time increment value corresponding to any speed value. In this chart the ordinates represent acceleration coefficients exactly as in the Chart of Coefficients, and the abscissæ represent time values in seconds, on a scale sufficiently large to indicate small fractional values of seconds. On this chart are drawn various reciprocal curves. The curve A is the true reciprocal curve, being obtained by dividing 1 by *each* acceleration coefficient value and plotting the resulting value. The curve B is a curve obtained in the same way, by taking *half* the reciprocal value. In like manner, we obtain the curves C, D, E, F, corresponding, respectively, to the 4/10, 3/10, 2/10, 1/10 reciprocal values, and the curves G, H, I, corresponding, respectively, to twice, five times, and ten times, the reciprocal value.

This chart is so prepared as to take advantage of the relation shown in Appendix C in equation (i), where the acceleration coefficient enters, it will be noted, as a *reciprocal*. The manner of using it is very simple. The acceleration coefficient value for any speed having been determined by means of the Chart of Coefficients, it is transferred by dividers, or in any convenient way, to the Chart of Reciprocals, where it is used as an ordinate value and moved sideways, as such, until it intersects the *proper* reciprocal line. The " proper " reciprocal line depends upon the speed differences or increments, as the equations in Appendix C clearly show. Consequently, with speed increments of

one mile per hour, curve A would be the proper curve; with speed increments of respectively, 1/10 m.p.h. and 10 m.p.h., the " proper " curves would be curves F and H. The smaller the speed increments, the more numerous will be the plotted points, and the greater the accuracy of the curve plotted. The process of determining, by means of these charts, the coördinate of a speed-time curve corresponding to any set of conditions, is so simple as compared with all previously known methods, that one can afford to use smaller speed increments and thus make the curve easier to draw and more accurate and satisfactory for any purpose.

It is important to note that the same reciprocal curve will not serve for all portions of a given speed-time curve, with equal accuracy, and that the reciprocal curves corresponding to relatively large speed increments (such as, for instance, curve I,) will be quite limited, both in application and in accuracy. This peculiarity, which is due to the form of the reciprocal curves, will be understood without difficulty, on glancing at the Chart of Reciprocals. It is seen that the higher acceleration coefficients (which correspond, as we know, to the more inclined portions of speed-time curves), have the short time-increment values, and that as the coefficient values become reduced (that is to say, as the speed-time curve " flattens "), the time increment values increase more and more rapidly. This relative increase in time increments continues until, for each reciprocal curve, in succession, beginning with curve I, which corresponds to the highest speed increments ($\Delta y = 10$ m.p.h.) and ending with curve F, which corresponds to the smallest speed increments ($\Delta y = 0.1$ m.p.h.) a point is finally reached at which the time-increment values obtained by reference to that particular curve would exceed the longest time value (9 seconds), which can be read on the chart. Thus, in the case of curve I, the chart limit would be reached when the acceleration coefficient became reduced to 1.11. This means that the curve I would be entirely useless for determining the time values of any speed-time curve or portion thereof not having an acceleration coefficient greater than 1.11. The chart limit for curve H would be, in like manner, an acceleration coefficient,

$$= \frac{5}{9} = 0.55$$

and the chart limit for any other curve would be

$$= \frac{\Delta y}{9}$$

where Δy = the speed increment corresponding to that particular curve. For example, in the case of curve A, where $\Delta y = 1$, the limit would be

$$\frac{\Delta y}{9} = \frac{1}{9} = 0.111$$

and for curve F where $\Delta y = 0.1$, the limit would be:

$$\frac{\Delta y}{9} = \frac{0.1}{9} = 0.011$$

These considerations clearly show that the reciprocal curves corresponding to the larger speed increments, such as curves G, H, I, can be used for determining the time-values only when plotting speed-time curves which have considerable slope or inclination (either upward or downward). It also becomes apparent that as the speed-time curve flattens, the reciprocal curves corresponding to smaller speed increments (such as B, C, D,etc.), become, first, desirable, then indispensable. For very accurate work the writer uses the curve A or the curve B for the highest accelerations (usually the curve A for coefficients above 2, and the curve B for coefficients between 1.5 and 2); and he uses, successively, the curves C, D, E, for intermediate lower coefficients, the curve F being used for the lowest coefficients. In cases when still greater accuracy is required than can be obtained with curve F, such as for plotting the nearly horizontal portions of speed-time curves (having coefficients approaching zero), the writer proceeds as follows: The net coefficient value, as obtained from the Chart of Coefficients by means of dividers or in other convenient manner, is increased twice, three times, or four times its value, and then used in the usual way for finding the time increment on the Chart of Reciprocals, by reference to curve F; the time value thus obtained is then divided by the multiplying factor used in enlarging the net coefficient, the result being the net time-increment value. A glance at the chart will readily show that this process is virtually the same as if a new reciprocal curve corresponding to smaller speed increments than the curve F were to be drawn. The method has the advantage over such a curve, however, that the coefficient is magnified, and that the time-increment reading is made at a point farther to the left, on the chart, where the reciprocal curves are farther apart, and where their inclination is greater, thereby enabling the reading to be made with much greater accuracy.

The five "observations" given at the end of appendix C, constitute rules which may be useful in selecting the proper reciprocal curves, for each particular case. Practical experience will, however, be the best guide.

Drifting Curves.—In the case of drifting curves, we have, as pointed out in equation (VII) to consider only the effects of the train resistance, track curvature and grades. The resultant acceleration coefficient at any speed is readily obtained from the Chart of Coefficients, just as in the case of acceleration curves. When the train is drifting and the energy required for turning the motors comes from the kinetic energy stored in the train, there is usually an increase in the train resistance due to the friction of the motor gears, etc., these motors being no longer electrically driven. The kinetic energy of the rotating parts, tends, in some measure, to counterbalance, or to neutralize, this increase. In case it is not fully neutralized, a new curve should be drawn, showing the acceleration coefficients corresponding to drifting and braking curves. The curve Q, as already stated, represents such a curve on the Chart of Coefficients. The values of the acceleration coefficient, as given on this curve, are the ones which should be taken in determining the resultant retardation graphically by means of this chart. The determination of the time increments is done in exactly the same manner as in the case of acceleration curves. Fig. 7 shows a set of nine drifting curves, including the drifting curve for a level and straight track, and eight curves, corresponding to up-grades and down-grades of, respectively, ½%, 1%, 1½% and 2%.

Braking Curves.—The coördinates of a braking curve should, in reality, be determined in substantially the same manner as the coördinates of acceleration and coasting curves. In order to do this, it would be necessary to draw on the Chart of Coefficients the curve of equivalent acceleration coefficents, corresponding to a given rate of braking. This curve would be almost, but not quite, a straight line parallel with the axis of x. The difficulty of this method is, that the form of brake lines varies so widely, and, at times, quite erratically. In practice, the process of plotting the braking curves is greatly simplified by making the assumption that the braking curve is a straight line. This is not exactly true, as already pointed out. In Fig. 3, the curve y, A, B, C is a true braking curve reproduced from an actual diagram obtained in the braking tests conducted by the New York Railroad Commission with various street-car brakes, in New York

City, in 1899. The dotted straight line, y, a, b, c, is the line enclosing the same area as the brake curve, this fact being clearly shown by the two distance curves o, e, f, g and o, e', f', g' on the lower part of the diagram. The first of these curves corresponds to the true brake curve, y, A, B, C, while the second corresponds to the equivalent brake curve, y, a, b, c. It will be seen that while the area enclosed by the two curves is exactly the same (being a trifle under .02 mile), the time required to cover this distance is greater in the case of the true brake curve than in the case of the modified one. In some cases, the time error resulting from the assumption of a constant rate of retardation, would be greater than in others, and might be serious. In most cases, however, it is negligible.

A closer approximation to the actual form of the brake curve can be made in the manner indicated in the right hand portion of Fig. 3, where the true brake curve y, a, b, c, and the straight line y, a, b, c, previously referred to, are both reproduced, together with the broken line, y, b', c. It will be seen that this broken line constitutes a much closer approximation to the actual brake curve than the straight line, y, a, b, c. The acceleration coefficient of the straight line is found by calculation to be, approximately, 1.84. The broken line has an acceleration coefficient of about 2.31 in the upper portion, and 1.2 in the lower portion. The two portions of the broken line, y, b' and $b' c$, correspond to equal "drops" or reductions of speed. It is seen that the acceleration coefficient (which, in this case, might better be called retardation coefficient), is about 25% greater, for the upper portion (y, b'), while the retardation coefficient of the lower portion ($b' c$), is nearly 40% less than the acceleration coefficient of the straight braking line, y, a, b, c. By sub-dividing the brake curve into three portions, the broken line, now consisting of three portions, would enable a still greater degree of approximation to the true curve to be obtained, as will be readily understood. Unfortunately, owing to the erratic variations in the form of the curve itself, it would be more difficult to assign proper values to the retardation coefficients of the different portions in terms of the retardation coefficient of the straight braking line (y, a, b, c), corresponding to the same distance. For this reason, the writer does not recommend sub-dividing the brake curve into more than two portions, and does not even recommend this except where extreme accuracy is desired.

The assumption that the braking curve is a straight line

greatly simplifies the process of plotting. The determination of the speed and time values, by which the line of braking may be drawn, comes under three general cases, constituting braking problems, which are treated and discussed as such in Appendix D.

It will be evident, of course, that the slope of the brake curve will still vary, even though the rate of retardation, due to the friction of the brake shoes, be assumed to be constant. This is apparent from equation (IX), in which it is seen that four factors (B, f, c, G,) enter into the equation for the retardation coefficient in braking. Owing, however, to the very fact that there is so much variation and uncertainty in the form of the brake curve, it is usual to make the assumption that a braking force of 150 lbs. per ton covers all three of the factors, B, f and c, for high-speed service. Hence, the only other force usually considered is the force of gravity (G). This, as we have already seen in Section I, enables equation (IX) to be simplified practically to the form shown in equation (X). The reason why the factor G is still retained and considered separately, is that the effect of gravity may be considerable on grades of relatively high percentage, and also that the effect would be opposite on up-grades and down-grades, respectively. In the case of the factors f and c, on the other hand, the effect is relatively small and always has the same sign. The force of gravity (G) being positive on down-grades will have the effect of neutralizing a part of the braking force applied. Thus, on a down-grade of 1 per cent., which corresponds, as already seen, to a tractive effort of 20 lbs., and taking, according to the usual practice, as stated above,

$$B - f - c = 150$$

the net braking effort would be

$$150 - 20 = 130 \text{ lbs.}$$

and the coefficient, which, in this case, might properly be called retardation coefficient, would be, according to equation (IV),

$$= .01098 \times 130 = 1.43$$

In the case of an up-grade of 1 per cent., the retardation coefficient would be equivalent to

$$= .01098\,(150 + 20) = 1.87$$

The value of k used in the equations given in Appendix D is understood to be, in every case, that which corresponds to the

resultant or net retardation, and it is determined in the manner just indicated.

It is seen that the foregoing method of plotting the braking curve still involves certain assumptions, which, in the present state of our knowledge, are unfortunately unavoidable. It is very much to be hoped that further experiments will be made for the purpose of determining the form of the true braking curve under various conditions of braking. It is also to be hoped that some convenient and practical means of analytical expression or of graphical representation of an *average* or *typical* braking curve may be arrived at. It is only then that it will be possible to eliminate the assumptions which now have to be made, and to attain a higher degree of precision in the plotting of the braking curve.

Distance-Time Curve.—Attention was called in Appendix A, in connection with equation (e), to the fact that the area of any portion of the speed-time curve comprised between two given intervals of time corresponds and is equal to the distance traversed by the moving body during that time. By taking advantage of this fact it is possible to plot on the same diagram on which the speed-time curve itself is drawn, another curve, the distance-time curve, usually called the "distance" curve. Such distance curves are shown in Figs, 1 to 4, inclusive. The coördinates for this curve are obtained, in each case, by integrating, successively, small strips of the area enclosed by the speed-time curve. This integration is usually done in practice by means of a planimeter or other integrating instrument. If, for example, we first integrate the portion corresponding to the first 20 seconds, the result obtained by the integration may be made a measure of the distance which the car will have traversed within the first 20 seconds. If, as pointed out in Appendix D, the numerical "area" result of the integration is divided by 3,600 (the number of seconds in one hour) the resulting figure will be the distance expressed in miles. Integrating, in like manner, the area comprised between 20 and 30 seconds we obtain the distance traversed in the interval of time comprised between the twentieth and thirtieth second. By integrating successively all the other portions of the speed-time curve between definite time limits in the same manner, other corresponding distance values (s) will be obtained. The total distance traversed will evidently be equal to the aggregate sum of all the separate distance values thus obtained. This total distance will be the highest point of the distance curve.

The object of integrating the area enclosed by the speed-time curve in separate strips, or "by parts," is, of course, to obtain the coördinates for various intermediate points on the curve, for the purpose of plotting the same. In plotting out the distance curve, the distance corresponding to the inferior time limit of integration (in equation [e], Appendix A) is equal to the so-called "constant of integration." Thus, in Fig. 4, in plotting the distance curve, *o-a-c-e*, between the points *a* and *c*, the distance value (*a*) obtained, as indicated in equation (*e*), by the integration of the acceleration curve from the beginning to the point *b*, would be equal to the constant of integration, which, in the case shown, is

$$a = \text{one mile},$$

and this value would have to be added to the distance value obtained by the integration of the portion of curve comprised between the points *b* and *d*, in order to give the total ordinate value or the actual location of the distance curve corresponding to the point *c*—that is to say, the ordinate at the upper limit of integration. This is evident, for, if the distance value obtained by integrating the area comprised between the points *b* and *d*, were to be plotted by measuring off from the axis of *x*, instead of from some point (*a*) higher up, it would then serve to indicate only the increase of distance covered between the points *b* and *d*. The addition of a distance value (*a*) equal to the distance already covered up to the point *b*, is necessary to bring the corresponding portion of the distance curve comprised between the points *b* and *d* into its proper place (*c*).

It is evident that the smaller the strips of area which are integrated at a time, and the more accurate the method of integration used, the more numerous will be the plotting points and the greater will be the accuracy with which the distance curve can be plotted. In the diagrams Figs. 1 to 4, inclusive, the distance curves are plotted so as to represent distances in miles, according to a scale of miles which is shown at the right-hand end of the diagram in each case. The process of computing the total area enclosed by the speed-time curve in very small portions is somewhat tedious. The work may be greatly simplified by the use of an instrument called the integraph, which was once exhibited, in 1888, before this INSTITUTE, by its learned inventor, the late Mr. B. Abdank-Abakanowicz. This instrument is an integrating instrument which, in addition to giving the numerical result of the integration, actually shows the steps of integration graphi-

cally, by drawing the so-called "integral" line. It is made in two sizes by Mr. G. Coradi, of Zurich, Switzerland, the distinguished maker of integrating instruments known by his name. The instrument admits of some range of adjustment, whereby the scale of ordinates may be varied. It is evident, however, that by means of proportional dividers, or by other well-known drafting-room methods, the scale of ordinates may be enlarged or reduced, so as to make it suitable for any scale desired for plotting the curve. The writer has made considerable use of the integraph during the last two years, and has found it exceedingly useful and convenient, not only on account of its precision but also as a time-saving device, in work of this character.

The distance-curve is of great utility in the plotting of the run-curves, because it constitutes the most practical means of determining the proper time points corresponding to a given distance. This is exemplified by means of the simple run-curve shown in Fig. 4. In plotting this run-curve it was desired to let the first or accelerating portion (which, as previously stated, was taken from Fig. 1), continue until a distance of exactly one mile had been covered. The dotted line b-a in Fig. 1, which intersects the distance-curve at a point (a) equal to a distance of one mile on the right-hand or "distance" scale, therefore represents the point at which the acceleration portion terminates. The drifting portion (B) of the curve in Fig. 4, was obtained by means of Fig. 2, beginning at a point (b) representing exactly the same speed as the point (b) in Fig. 1. The line b-a in Fig. 2 intersects the distance-curve at the point a. It being desired to let the drifting portion (B) of the run-curve also represent the same total distance traversed, exactly one mile, this curve was cut off in Fig. 2 at the point (d), so located that the last ordinate would intersect the distance-curve, in Fig. 2, at a point (c) whose vertical distance (c, c') above the starting point (a) was equal to one mile, when measured on the distance scale. The portion of the distance-curve in Fig. 2, comprised between the points a and c, could, therefore, be reproduced in Fig. 4, starting from the point a. It is seen that the point c, in Fig. 4, corresponds to a distance of exactly two miles on the distance-scale. The distance-curve constitutes a convenient means, and the most practical means, whereby the various kinds of curves may be cut off and connected at the proper points in assembling them together to form the run-curves. This will be further exemplified hereinafter in discussing the plotting of a service run-curve, constituting a practical illustration of the process of plotting such curves.

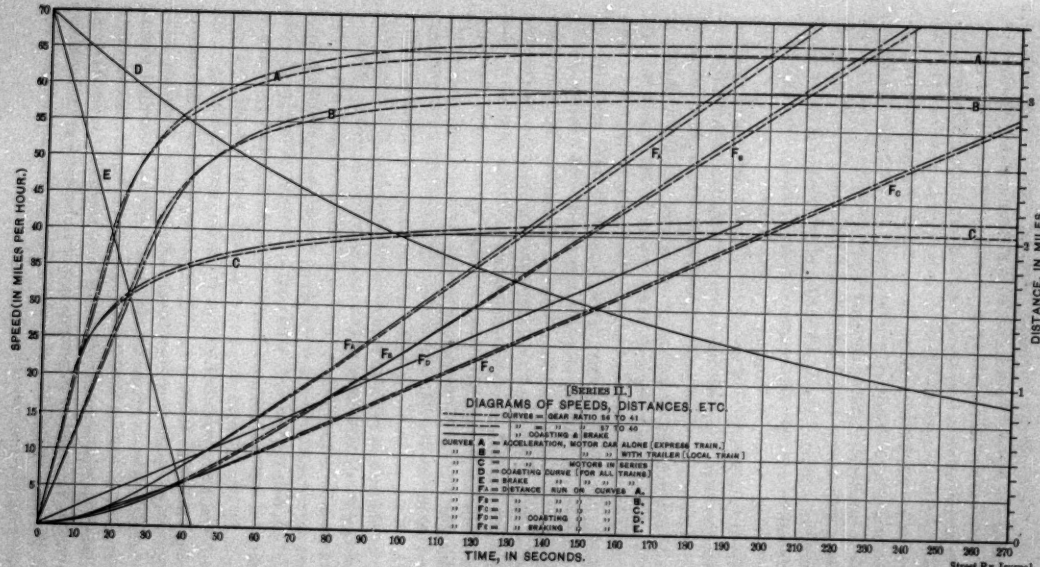

SPEED (IN MILES PER HOUR.)
TIME, IN SECONDS.
DISTANCE, IN MILES.
A
B
C
D
E
F_A
F_B
F_C
F_D
F_E
F_F
[SERIES II.]
DIAGRAMS OF SPEEDS, DISTANCES, ETC.
CURVES = GEAR RATIO 56 TO 41
" = " 37 TO 60
" COASTING & BRAKE
CURVES A = ACCELERATION, MOTOR CAR ALONE [EXPRESS TRAIN.]
" B = " " WITH TRAILER [LOCAL TRAIN]
" C = " MOTORS IN SERIES
" D = COASTING CURVE [FOR ALL TRAINS]
" E = BRAKE
" F_A = DISTANCE RUN ON CURVES A, B, C, D, E
" F_B = " " " " " "
" F_C = " " " " " "
" F_D = " COASTING " " "
" F_E = " BRAKING " " "
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FIG. 11.

From the above it will be seen that the speed-time curve establishes a relation between the distance, speed, and the time, in any given case. Hence, if any two of these three quantities are given or assumed the third can be determined. In the majority of cases the distance is known, at least approximately. The quantities to be determined by means of speed-time curves are either the speed to be obtained, when the time is assumed or known, or else the time required for a given service, when the speed is known or assumed.

Modified Curves.—Fig. 11 is reproduced for the purpose of illustrating the modifications produced in the acceleration curve and the distance-curve by various changes in service conditions. The lower "*A*" curve is the same as the solid line curve in Fig. 7. The lower "*B*" curve shows the change in the form of the acceleration curve produced by the addition of a trailer-car to the motor car. It bears a relation to the curve *A* similar to that of a curve for an up-grade of relatively high percentage, this relation being obvious from the analytical principles previously set forth. The lower curve, *C*, shows the acceleration which would be obtained if the motors remained connected in series throughout the acceleration cycle. The curves *Fa*, *Fb*, *Fc*, etc., are the corresponding distance-curves. In the case of both acceleration and distance-curves the upper line of each pair is that which corresponds to the next higher gearing ratio. It should be noted that while the maximum speed attainable is higher with an increased gearing ratio, yet the initial acceleration is smaller. The two acceleration curves of each "pair," and the two corresponding distance curves, cross, in the figure, at a point near the bend or "knee" in the curve. This characteristic feature of the two curves is the reason why the higher gearing ratio would be selected when the lengths of run are relatively great, whereas the lower gearing ratio would be selected when the lengths of run and the time allowable for acceleration are relatively short.

Run-Curves.—The process of plotting a run-curve consists in selecting and in bringing together properly, certain determinate portions of acceleration curves, drifting curves and braking curves, constituting its component parts.

The operation of selecting and plotting the portions of component curves aforesaid, naturally involves a more or less comprehensive study of all the basic data, the peculiar features and the specific conditions of the case, as well as the determination of their influence and effects by reference to the principles of analysis

and synthesis previously considered; and it also requires the practical application of methods of plotting such as hereinbefore described. The operation of bringing together and of combining the component curves, involves the utilization of the distance-time curve as a gage of the distance and time intervals corresponding to each distinct portion of curve; and it requires some knowledge of drafting room methods.

In a conventional run-curve of the simplest form, such as shown in Fig. 4, there are only three component parts (A. B, C), which are easily combined together in the manner already explained in Section 1. Such a run-curve, however, only applies when the track actually is, or is assumed to be, straight and level. When it is desired to make proper allowance for track curves and grades, the process of producing the run-curve is no longer as simple.

Fig. 12 shows a " service " run-curve in which the speed line is modified by grades only. It represents express service run No. 7, running north, on the New York & Port Chester Railroad.

Fig. 13 shows a " service " run-curve in which the speed line is modified both by grades and track curves. It represents express service run No. 11, running south, on the same line.

The latter curve has been specially selected as an interesting practical example of speed-time curve plotting, embodying substantially all the features and complications which are usually met with in the plotting of such curves.

These two service-run curves form part of a large series of such curves prepared for the aforesaid company during the last year, under the joint direction of Mr. W. C. Gotshall, president of the company, and the writer, to serve as the basis and also as the corroboration of technical evidence regarding the engineering features and merits of the project of the company, as presented in the hearing before the New York State Railroad Commission; and they are here reproduced, together with some of the corresponding subsidiary curves, by permission of Mr. Gotshall. The writer further takes this occasion to acknowledge many valuable ideas and suggestions kindly given by Mr. Gotshall, and gladly utilized in the preparation of this paper.

Tables I. and II. give the line data which are the basic data by reference to which these two run-curves were prepared. These data were taken or calculated from the profile maps, location maps and field notes of the preliminary surveys made of the entire line. The first column gives the reference letters by means of

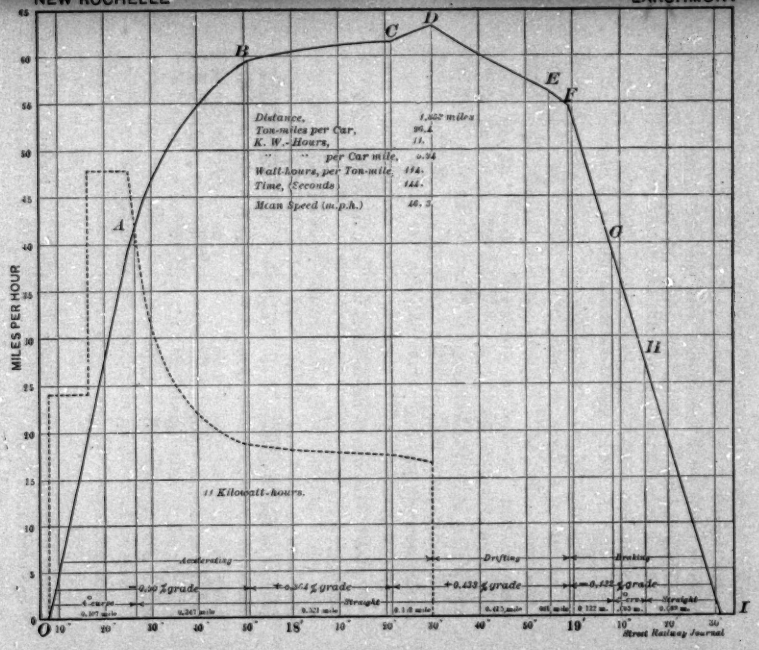
NEW ROCHELLE
LARCHMONT
MILES PER HOUR
Distance, 1.322 miles
Ton-miles per Car, 96.2
K. W.-Hours, 11.
" " per Car mile, 0.24
Watt-hours, per Ton-mile 114.
Time, Seconds 111.
Mean Speed (m.p.h.) 42.7
11 Kilowatt-hours.
Accelerating
Drifting
Braking
+0.90 % grade
+0.314 % grade
+0.433 % grade
-0.422 % grade
4° curve
Straight
Straight
Straight
Street Railway Journal

FIG. 12.

which the corresponding portion of the run-curve in the figure may be identified. Column II. gives the lengths of the corresponding portions of the total run in fractions of a mile. Columns III. and IV. give the percentages of up-grade and down-grade, respectively. Column V. gives the track curvature, stated in track "degrees," the word "tangent" being synonymous with "zero degrees" (0°), and being used to designate *straight* portions of track, all in accordance with the established practice in civil engineering. Column VI. gives the track curvature ex-

Table I.—Line Data for Express Service Run No. 7 (North) New York & Port Chester Railroad Co.

I.	II.	Per Cent. of Grade		Track Curvature		VII.
Portion No. (Fig. 12)	Length Miles	III. Up	IV. Down	V. Degrees	VI.* Equival't Grade %	Net Equivalent Grade
0 to A	.107	....	0.900	4°	+0.180	+0.720%
A o B	.347	....	0.900	Tangent	.....	−0.900%
B to C	.521	0.364	....	"	.....	+0.364%
C to E	.567	....	0.433	"	.....	−0.433%
E to G	.183	0.122	....	"	.....	+0.122%
G to H	.065	0.122	....	2°	+0.090	+0.212%
H to I	.063	0.122	....	Tangent	.....	+0.122%
	1.853	....	....	.....	.....	.....

Table II.—Line Data for Express Service Run No. 11 (South) New York & Port Chester Railroad Co.

I.	II.	Per Cent. of Grade		Track Curvature		VII.
Portion No. (Fig. 13)	Length (Miles)	III. Up	IV. Down	V.	VI.* Equival't Grade %	Net Equivalent Grade
0 to A	.306	0.283	....	Tangent	.....	−0.283%
A to B	.113	0.283	....	1° 30′	+ .068	+0.351%
B to E	.374	0.283	....	Tangent	.....	+0.283%
E to H	.208	0.283	....	7° 10′	+0.323	+0.606%
H to I	.135	0.283	....	Tangent	.....	+0.283%
I to J	.189	Level	....	"	.....	.....
J to M	.189	1.300	....	"	.....	+1.300%
M to N	.111	Level	....	"	.....	.....
	1.625	....	....	.....	.....	.....

*By equation (XII), taking b = 0.9

pressed in equivalent percentage of grade. In Column VII. the "net equivalent grade" values are given, these values being the same as the grade values given in Column III., for all portions on which there are no track curves, and being equal to the algebraical sum of the values given in Columns III. and VI. for all portions of the run on which track curves occur.

It will be noted that in the tables the total length of run is subdivided into as many portions as there are changes in track

gradient or in track curvature. each portion being tabulated separately in a distinct line. Each of the lines in the tables corresponds to at least one " component " portion of the run curve. Some of them may correspond, as will be seen later, to two or more such component portions. Thus, while the total distance for run No. 7, amounting to 1.853 miles, in Table I., is sub-divided into seven distinct portions, each tabulated in a distinct line, it will be found that the corresponding run-curve (Fig. 12) is made up of nine " component " portions of run. In like manner the eight distinct portions of the run (No. 11) tabulated in Table II., correspond to fourteen " component " portions of run in Fig. 13.

The manner in which the aforesaid line " characteristics " influence the form of the speed-time curve has already been fully considered. In plotting a run-curve we need, it is obvious, to consider in addition to these line data, the other forces concerned in acceleration. If we use the " chart " method, previously described, we will need a " Chart of Coefficients," on which will be drawn the proper curves analogous to M and N, giving, respectively, the gross and net motor accelerations as functions of the speed, and also the curve R, giving the equivalent acceleration due to train resistance. The " corrected " speed curve and the tractive-effort curve marked " C " in Fig. 5, constitute the motor characteristics, by reference to which the curve of gross acceleration coefficients (M), shown in Fig. 9, was prepared. This curve (M) is substantially the same as was used in plotting the set of acceleration curves corresponding to various gradients, shown in Fig. 7, and the service-run curves, shown in Figs. 12 and 13.

It is proper to state that the straight portion of this curve M is based upon the assumption that the mean value of the current during the early stages of acceleration will be exactly 400 amps. per motor, corresponding to a maximum initial tractive effort of 2644 lbs. per motor,as indicated by the corrected curve of tractive efforts (C) in Fig. 5.

The track curves occurring during a given run are the first features requiring attention. If the track curves occur at the beginning or at the end of the run they usually impose no limitations on the speed. When they occur at midway points on the run they will impose limitations unless they are of relatively small degree. Run No. 11 furnishes an instance of this kind, as will be seen later.

Service Run No. 7.—(Fig. 12) begins with a portion, 0.107 mile

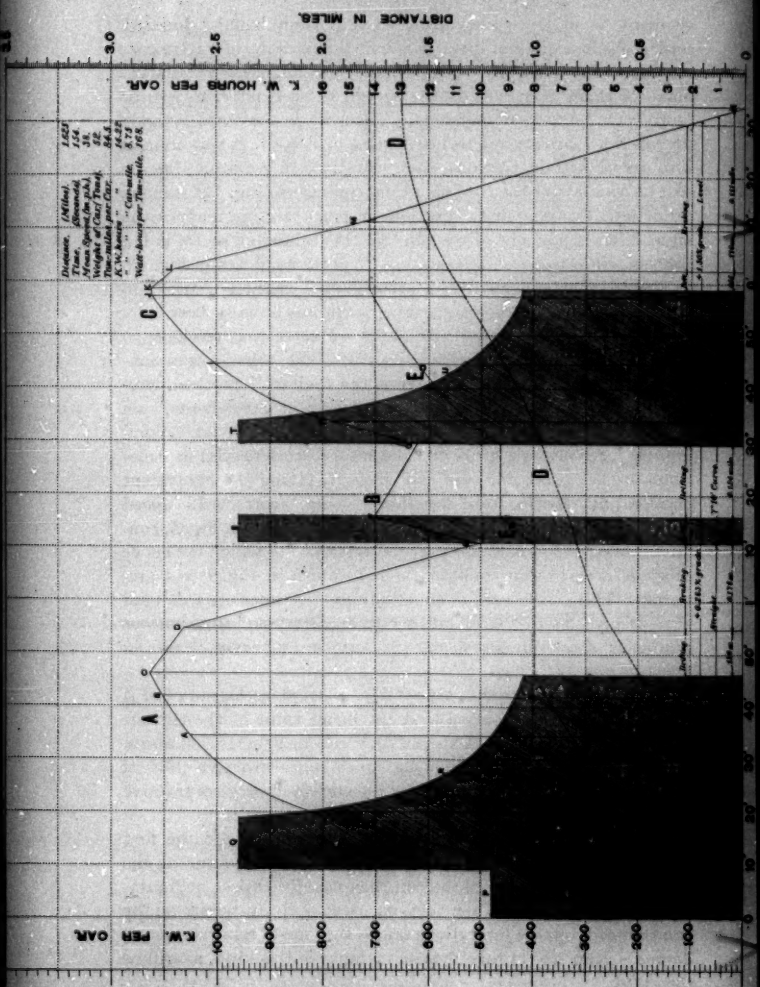
SPEED, MILES PER HOUR.
K.W. PER CAR.
K. W. HOURS PER CAR.
DISTANCE IN MILES.
A
B
C
D
E

FIG. 13.

in length, having a track curve of 4 degs. and a down-grade of 0.90%. The data in Column VI, giving the "equivalent grade," and in Column VII, giving the "net grade," show that the advantage of the down-grade is partly offset by the increase in the train resistance due to the track curve, the resultant effect being the same as if the track were straight and had a down-grade of only 0.72% instead of 0.90%. The first portion (*O-A*) of the service-run curve in Fig. 12 will, therefore, be the same as the first portion of an acceleration curve, such as would be obtained on a straight track having a down-grade of 0.72%. The net acceleration coefficients for this portion of the curve may, it is obvious, be readily obtained from the "Chart of Coefficients" (Fig. 9), and the corresponding time values can then be obtained by reference to the "Chart of Reciprocals" (Fig. 10) in the manner already fully explained.

The process of determining the coördinate points for the portion of curve to be plotted has already been described fully in the previous pages, and, therefore, need not be detailed further. The coördinates of the curve having been determined and the curve itself having been plotted and drawn, the next step is to ascertain the exact point at which the first portion (*O-A*) terminates. This is done by means of the distance-curve, in the manner already fully explained, and also illustrated by reference to Fig. 4 in the foregoing reference to the "distance-time curve." The time point at which the ordinate of the distance-curve, when measured by the scale of distance, indicates a distance of 0.107 mile, represents the time point at which the first portion of the run-curve (*O-A*) should terminate. A vertical ordinate line is usually drawn from the terminal point *A* after it has been thus determined. The end of the first portion of the run (*A*) corresponds to a speed of 41.8 m.p.h.

The second portion of the run has, according to Table I., a length of 0.347 mile, with the same down-grade (− 0.90%) but without any curve. It begins at the speed point *A* (= 41.8 m.p.h.) and ends at the point *B* (= 59.6 m.p.h.), The coördinates for this portion of the curve are to be determined in substantially the same way as for the first portion of the curve, with the exception that the time values for all speed points higher than 41.8 m.p.h. are the only ones which need to be determined. After the curve has been plotted and drawn to a certain length, the point *B*, at which it should be cut off, is determined by reference to the corresponding distance-curve. The third portion of

the curve, as shown in Table I., is 0.521 mile in length, straight and on an up-grade of 0.364%. The coördinates for this portion of the curve are determined and plotted, and the terminal point (C = 61.7 m.p.h.) is determined in the same manner as before. The relative flatness of this portion of the curve is both the result and the indication of the effect of the up-grade, the relative gain in speed being, as should be expected, much less on an up-grade than on a down-grade.

As the three portions of run-curve thus far considered cover a little over one-half of the total distance, it becomes necessary, in proceeding to plot the next portion, to anticipate and to determine two things: First, the point at which the electric power is to be shut off and at which the train will begin to coast; and, second, the point at which the brakes will be applied. Both points are determined somewhat arbitrarily, and vary greatly in different cases. It may be said that both are related to, and depend upon, the time allowed for making the run, or, in other words, the schedule speed required. The sooner the electric power is shut off the smaller, it is obvious, will be the amount of electric energy consumed during the run. The effect of cutting off the electric power early is to increase the length of time during which the train must drift or coast, and also to lower the speed at which the brakes must be applied, in order to cover the same given total length of run. When economy is an important consideration it is obviously desirable that the amount of coasting should be greatly increased, and that the braking should begin at as low a speed as possible, for, the greater the amount of speed reduction obtained by drifting or coasting, and the lower the speed at which the brakes are applied, the smaller the momentum of the car at the time of braking, and, consequently, the smaller the amount of energy dissipated by friction during the operation of braking. When time is an important consideration, however, as in the case of a rapid transit or express line, it becomes necessary to sacrifice economy in order to gain time. In such cases we must shorten considerably the period of time during which the train will coast, and we must begin the operation of braking at a much higher speed. It may be desirable, in fact, to reduce the period of braking until it is virtually eliminated, the brakes being practically put on at the same instant that the power is shut off. A run-curve made under those conditions will be the curve corresponding to the *minimum time of run* for that particular case, although it will not be the curve of *minimum energy consumption*.

It is desirable, even when the quickest time is to be made, to still make allowance for a certain period of coasting between the time that the power is shut off and the time that the brakes are applied. This gives the motorman a certain margin, for, if running behind, he can keep the current on a little longer and reduce or eliminate, the period of coasting, while if running ahead, he can cut off the power earlier, and increase the period of coasting. In the service run under consideration (Fig. 12), the acceleration is continued on entering the fourth portion of the run (C to E), until the point D, distant 0.152 mile from the point C, has been attained. At the point D ($= 63.3$ m.p.h.) the current is shut off and the train begins to drift. In this particular case it was decided to let the coasting continue until the speed became reduced to 55 m.p.h., at which point (F) the operation of braking is to begin. The fixing of the braking point has the effect of also fixing the point D, at which the current is to be cut off. This is due to the fixed relation between the form of a speed-time curve and the area enclosed by it, and also to the fact that this area, as pointed out in Appendix A, is equal to, and serves to measure, the distance covered by the train in the corresponding time interval.

The fourth portion (C to E) of the run tabulated in Table I, will, therefore, correspond to two "component" curves, one being an acceleration curve (C-D), and the other a drifting curve (D-E). The acceleration curve is to be determined and to be plotted in the manner indicated for the preceding portions. As the point D is not known and has to be determined, it will be necessary to plot the curve to some arbitrary length, such as may be deemed sufficient for the purpose. If too long, the excess can be erased; if too short, it will have to be lengthened.

The point D, at which the drifting begins, cannot be determined until we ascertain how much distance will be covered by the train while braking from the speed of 55 m.p.h., which, as already stated, was fixed as the point at which the operation of braking is to begin. It will be necessary, therefore, to determine and even to plot out the braking curve before plotting the drifting curve itself.

In plotting the braking curve we have to work backwards, so to speak, for we must, of necessity, begin with the last portion. According to Table I, the last portion of the run is straight, on a $+ 0.122\%$ grade, and it is .063 mile in length. We need to determine, first, the speed at which the train would be running at the time of entering this portion; second, the time consumed in

running through this portion. This case corresponds exactly with the first brake-curve problem discussed in Appendix D. The equations (*e*) and (*f*) therein obtained for the speed and time values will exactly apply in this case. The speed will be:

$$y = \sqrt{7200\, k\, s} \qquad (e)$$

and the time will be:

$$x = \frac{y}{k} = \frac{\sqrt{7200\, k\, s}}{k} \qquad (f)$$

in which

y = the initial braking speed for that portion of the run.
x = the time interval for that portion of the run.
k = the net or resultant retardation coefficient.
s = the length of the corresponding portion in miles.
= .063 mile, in this case.

The value of the retardation coefficient, k, when calculated by the formula given in equation (*X*), will be found in this case to be:

$$k = 1.647 + (0.01098 \times 0.122 \times 20) = 1.674$$

Substituting the proper values in equation (*e*) we have:

$$y = \sqrt{7200 \times 1.674 \times 0.63} = 27.6 \text{ m.p.h.}$$

(which is the speed at the point H); and the time, by equation (*f*),, will be:

$$x = \frac{27.6}{1.674} = 16.5 \text{ seconds.}$$

We next proceed to determine the coördinates for the portion of run ($G\,H$) immediately preceding the last portion.

The case corresponds exactly with Problem 2 in Appendix D. The initial speed (at the point G) will be

$$Y = \sqrt{7200\, K\, s + a^2} \qquad (l)$$

where

Y = the entering or initial speed.
a = the leaving or final speed.
s = the distance.
k = the net coefficient of retardation.

The final speed (a) will obviously be the same as the initial speed y (= 27.6 m.p.h.) for the last portion of the run.

The distance, from Table I, is

$$s = .065 \text{ mile.}$$

The net retardation coefficient for the " equivalent " grade given in Table I., Column VII., will, by equation (X), be

$$k = 1.647 + (.212 \times .20 \times 0.01098)$$
$$= 1.694$$

Substituting these values in equation (l) we will have:

$$Y = \sqrt{7200 \times 1.694 \times .065 + 759.3}$$

$$= \sqrt{792.7 + 759.3} = 39.4 \text{ m.p.h.}$$

(which is the speed at the point G).

The time interval corresponding to this portion of the run will be:

$$x = \frac{Y - a}{k} \qquad (i)$$

$$= \frac{39.4 - 27.6}{1.694} = 6.97 \text{ seconds}$$

or practically 7 seconds.

The speed at the point G being only 39.4 m.p.h., as already seen, it follows that the braking must have begun before the train enters upon the portion $G\,H$. The next step, therefore, is to determine how much of the portion ($E\,G$) preceding the portion $G\,H$ will be covered by a train when braking a long enough time to reduce the speed from 55 m.p.h. to 39.4 m.p.h. This case corresponds exactly with problem 3 in Appendix D. The formula for the distance traveled is

$$s = \frac{Y^2 - a^2}{7200\,k} \qquad (m)$$

where

Y = the initial braking speed.
a = the final braking speed.
k = the net retardation coefficient.
s = the distance traveled while braking from speed " Y " to speed " a."

The net equivalent grade (Column VII.) being the same for this portion as for the last portion ($H\,I$), the net retardation coefficient will also be the same, or $k = 1.674$.

Substituting values in equation (m) we have:

$$s = \frac{55^2 - 39.4^2}{7200 \times 1.674} = .122 \text{ mile}$$

which is the length of that part of the portion of run $E\,G$.

This, as we find from Table I., is not the whole of the portion of run $E\,G$, which is 0.183 mile long. The difference, which is

$$0.183 - 0.122 = 0.061 \text{ mile},$$

represents distance covered by the train *before* the braking begins, or, in other words, while the train is still drifting. Hence the portion of run $E\,G$ must be represented in the run-curve by two "component" curves, one ($E\,F$) being a drifting curve and the other ($F\,G$) being a braking curve. The time interval corresponding to the portion $F\,G$ is calculated in the same manner as for the portion $G\,H$ by means of formula (i). Its value is

$$x = \frac{55 - 39.4}{1.674} = 9.3 \text{ seconds}$$

The next step is to plot a portion of the drifting curve from which the portion $E\,F$ may be cut off. This can be done by the chart method, using the curve Q on the chart of coefficients. We may begin plotting from a slightly higher speed, say 57 m.p.h. or 58 m.p.h., and plot the curve downward with positively increasing time values, in the usual way, until the speed line comes down to 55 m.p.h.—where the drifting ceases.

We may, however, plot the drifting curve in the opposite direction or "backward" as it were, starting from the lower speed limit (55 m.p.h.), and continuing upward and backward until the length of the portion plotted is sufficient to represent a little more than the distance required to be covered. With a little practice, it is as easy, by the chart method to plot a curve "backward," as it is to plot it "forward." This is one of the incidental features and advantages of the method. The *modus operandi* when plotting backward is, in reality, exactly the same, but the *order* is reversed. In plotting a drifting curve "forward," the retardation coefficient values would be taken from the chart of coefficients in the order of *descending* speed values, or from right to left, and the summated values would be reckoned and plotted in the right-hand direction, like positive abscissæ. In plotting "backward," we merely reverse this order; the retardation coefficients are taken from the chart of coefficients in the order of *ascending* speed values, and the summated time values are to be reckoned and plotted in the left-hand direction, as if they were negative abscissæ.

The curve having been plotted (on a separate sheet) the next

step is to determine the " entering " point (E), at which it should be cut off. This is to be done, as in the case of the three portions of acceleration curve (O to C), by reference to the distance curve corresponding to this drifting curve. The initial or entering speed (at the point E) is found to be 56.4 m.p.h.

We now come to the final and somewhat difficult operation of making the " joint" or connection between what might be termed the " acceleration end " and the " retardation end " of the run-curve. This joint occurs, as already seen, at a point D, on the portion $C\,E$. which point is, itself, to be located. It is necessary in this case to operate from both ends of the portion of run $C\,E$. For this purpose we need an acceleration curve suitable for the beginning of this portion, and a drifting curve suitable for the end thereof. Suppose we plot, in accordance with the data given in Table I., for the portion $C\,E$, on separate sheets of tracing paper or of tracing cloth, two distinct speed-time curves—one being an *acceleration* curve whose " beginning " or lowest speed point is the same as the speed at the point C (= 59.6 m.p.h.)—the other being a *drifting* curve, whose " end " or lowest speed point is the same as the speed at the point E (= 56.4 m.p.h.); and suppose the distance curve for each speed-time curve to be also drawn on the same sheet therewith. If the two sheets be placed in correct ordinate relation with a straight line serving as the axis of x for both curves, the acceleration curve being placed at the left and the drifting curve at the right, and if they be then moved toward each other until they become partially superposed, the upper ends of the two curves will eventually come in contact; and if the sheets continue to move toward each other, the point of intersection between the two speed-time curves will gradually become lower, until it corresponds exactly with the right speed point D, at which point the motion should stop. When the two curves are in this relation, they will precisely represent the portion of the run $C\,D\,E$ shown in Fig. 12,and it will be found by reference to the distance-curves, that the aggregate distance corresponding to the two component curves $C\,D$ and $D\,E$ will be exactly 0.567 mile, as given in Table I. It is evident that if the curves were made to intersect at a point higher than the point D, the aggregate area, and, consequently, the aggregate distance covered by the two curves would be greater, whereas, if the curves were moved closer together, thereby bringing the point of intersection below the point D, the area enclosed, and, consequently, the distance covered would be smaller. The point D is, therefore, the only one

which meets the condition. It will be found that the acceleration portion, *C D*, ends when a speed of 63.3 m.p.h. has been attained and a distance of 0.152 mile has been covered, the rest of the distance (0.415 mile), being covered while drifting from this speed to the entering speed at the point *E* (56.4 m.p.h.).

The component curves *C D* and *D E* having been determined, they can now be plotted on the same sheet as the preceding portions of the run-curve. The portion *E F*, plotted on a separate sheet, may now be transferred to the same sheet. The portions of braking curve, *F G*, *G H* and *H I*, being straight lines, can be readily plotted by reference to the data calculated in the manner previously indicated. Thus, the point *G* corresponds to a speed of 39.4 m.p.h. and a time distance of 9.3 seconds from the ordinate of the point *F*. In like manner, the point *H* corresponds to a speed of 27.6 m.p.h., and a time distance of 7 seconds from the ordinate of the point *G*. The terminal point *I* occurs at a time distance of 16.5 seconds from the ordinate of the point *H*.

Service Run No. 11 (*Fig.* 13).—A glance at the curve shows that it has two " notches " and three "crests."*A*, *B*, *C*, indicating three distinctive acceleration cycles. The acceleration in the first cycle lasts from the time of starting until the speed point *C* (56.35 m.p.h.) is attained, after which the train drifts as far as the point *D* (53.2 m.p.h.), and then brakes as far as the point *E* (25 m.p.h.), where the second cycle begins. The acceleration in the second cycle continues until the speed has risen to the point *F* (35 m.p.h.), after which the train drifts to the speed point *G* (31.1 m.p.h.), where the third cycle begins, with acceleration continued to the speed point *K* (56.2 m.p.h.), followed by drifting to the point *L* (54 m.p.h.), at which point the final braking begins, being continued to the end of the run (*N*).

The striking difference in outline between this run-curve and the run-curve shown in Fig. 12, is due to the restriction imposed upon the speed by a track curve of relatively short radius (7° 10′), which occurs in the portion *E H*, about midway in this particular run. It will be found by reference to the line data in Table II., that there are two track curves in this run. The first track curve (1° 30′) occurring in the portion *A B* and tabulated in the second line in Table II., does not impose any limitations on the speed, such track curves being considered safe at any speeds below 60 m.p.h. In the case of the second track curve (7° 10′), however, it is necessary to restrict the speed considerably. It was decided in this special case that the speed on entering this particular

track curve ought not to exceed 25 m.p.h., and that the speed ought not to exceed 35 m.p.h. while running on the curve, excepting toward the end, where it would be allowable to permit the speed to rise as high as 40 m.p.h. while running out of the track curve. This restriction, it will be readily seen, accounts for the notch at the point E, as well as for the crests B C, in the run-curve. This case is an interesting illustration of the important modifying effect produced on the service run-curve by a track curve of relatively small radius occurring at a midway point in the run. The track curve is, in this case, the primary cause for the two supplemental accelerations required in this particular service run, each of which involves an application of electrical energy to the train, and, consequently, occasions a material increase in the energy consumption required for the run, as will be found later, on plotting the power input curves.

When the service run has but a single cycle, as in Fig. 12, the plotting must of necessity begin with the very first portion. When it has several acceleration cycles, as in this case, if the speed value at the beginning of the second or third cycle is determined, or arbitrarily fixed, it is possible to begin the process of plotting at one of these cycles. Thus, in this particular case, the speed being restricted and set to 25 m.p.h. at the point E, corresponding to the point at which the train enters the sharp track curve, it would be possible to begin the process of plotting the run-curve from the point E instead of from the point O. Advantage may be taken of this fact when it is desired to do work quickly, and to apportion it among as many persons as possible. In this case we shall follow the usual practice and assume that the curve is to be plotted by beginning at the very first portion (O A).

The operation of plotting the run-curves is susceptible of being still further simplified, especially when the run-curves are plotted and drawn on a relatively large scale, by a "method of interpolation," which the writer has used considerably, with success and satisfaction. The method is specially useful when the number of run-curves to be made is large. For the purpose of giving an example illustrating the nature and practical use of the method, it will be assumed to be the method used in plotting the service run-curve shown in Fig. 13.

The *Interpolation Method* is one in which the "component" curves are obtained by the modification of certain "fixed" reference curves. The method requires a "Chart of Accelera-

tions," such as shown in Fig. 7, and a "Chart of Retardations," such as shown in Fig. 8. Each chart should contain various speed-time curves corresponding to several up-grades, to zero grade (level track), and to several down-grades, together with the distance-time curve corresponding to each speed-time curve. The curves in Figs. 7 and 8 correspond, as already stated, to "zero" grade, and to 0.5%, 1%, 1.5% and 2% of both up-grade and down-grade, the down-grade curves being *above* and the up-grade curves *below* the curve for level track, in both cases. The speed-time curves in both charts can be readily and quickly plotted by the "chart method" hereinbefore described. Where greater refinement is desired, the curves may be plotted for every fifth of a per cent. instead of every half per cent. of grade. The distance curves are plotted from coördinates obtained by the integration of the corresponding speed-time curve by the planimeter or by the integraph, in the manner already explained. The scales of speed and time values used on these charts should, for obvious reasons, be exactly the same as those used in the run-curves.

It may be interesting to note the fact that the acceleration curves in Fig. 7 have all been plotted on the assumption that the curve N on the Chart of Coefficients (Fig. 9) begins at the point a instead of the point b. This means that no allowance has been made in the curves for the increase in train resistance due to static friction at the time of starting. Theoretically, the dip in the curve N at the point b should cause a short bend convex to the axis of x in each acceleration curve, such that a line tangent to the straight portions would not pass through the origin of x but through some point to the right of it. It will be doubtless interesting and perhaps reassuring to learn that, practically, the error resulting from the assumption aforesaid is less than one-twentieth of a second, and is consequently negligible even when the time values a and b have been determined by the curve of reciprocals giving the greatest accuracy (F in Fig. 10), and further, that the discrepancy in time values practically vanishes when using reciprocal curves corresponding to speed increments of 0.5 m.p.h. or 1.0 m.p.h. (curves B and A).

Fig. 14 gives an enlargement of the portion of Fig. 7, containing the speed-time curves comprised between the speeds of 45 m.p.h. and 60 m.p.h. and the time interval between the twentieth and fiftieth second of time, and also an enlargement of the corresponding distance-time curves. The heavier lines represent portions of run-curve referred to later.

In using the interpolation method it is necessary to first plot the run-curve upon tracing paper or tracing cloth, after which the curve may be transferred to or reproduced upon another sheet, if desired. A tracing sheet having been placed upon the Chart of Accelerations (Fig. 7) we proceed to plot thereon the portion of run-curve corresponding to the portion *O A* of service run No. 11. The run-curve over this portion will, obviously, begin at zero speed. The form of the curve will depend upon the "net equivalent grade" for this portion, which, according to Table II., is + 0.283%, or the same as the actual grade, there being no track curvature. If an acceleration curve for this gradient be plotted in the regular way by the "chart method" beginning the plotting on the tracing sheet at the same point as the acceleration curves on the Chart of Accelerations, this curve will be found to pass between the curve for a level track (solid line) and the curve for a one-half per cent. grade (first dotted line below the solid line), being slightly nearer the dotted line curve than the solid line curve. Let us now proceed to plot the same curve by "interpolation" between the solid line curve and the first dotted line curve. Since 0.283 of *one* per cent. is equal to $0.283 \times 2 = 0.566$ of *one-half* per cent., it follows that the interpolation points will be 0.566 of the space between the two curves aforesaid, reckoning from the solid line curve. In this way any desired number of points may be located between the two curves. In practice the work of doing this may be simplified by using proportional dividers adjusted for the ratio 57:100, or by using proportional scales or other methods of proportional subdivision, well known in the drafting-room. On drawing this curve it will be found to coincide very closely with the curve previously plotted by the chart method. The divergence between the two curves represents the error due to the interpolation method. This error, however, is so slight that, in most cases, it may be considered negligible.

The method of interpolation may also be applied to the distance time curve. The method would, in fact, have relatively little value if this could not be done—its principal advantage being to simplify the operation of "cutting off" each portion of the curve at the proper distance points.

The distance curve corresponding to any interpolated acceleration curve is also prepared by interpolation in exactly the same way as the acceleration curve.

In Fig. 14, in the upper portion of the diagram, the line drawn

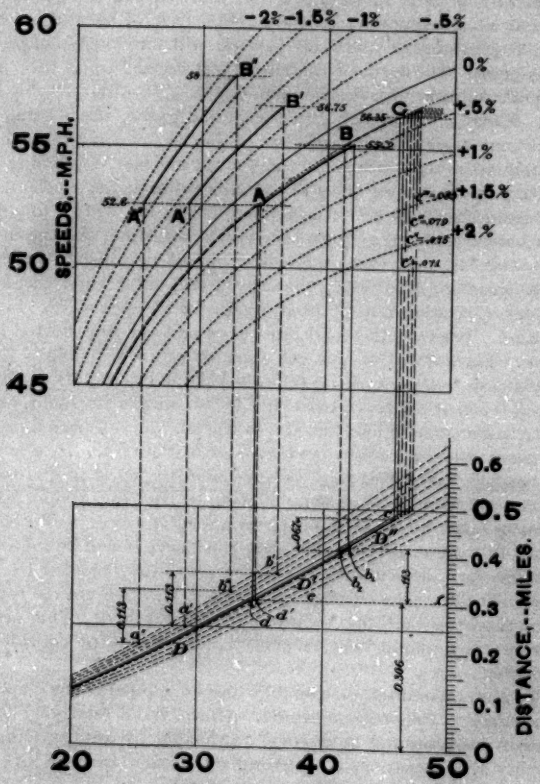
-2% -1.5% -1% -.5%
0%
+.5%
+1%
+1.5%
+2%
60
55
50
45
SPEEDS.--M.P.H.
B''
B'
B
C
A'
A
52.6
58
54.75
58.35
0.6
0.5
0.4
0.3
0.2
0.1
0
DISTANCE.--MILES.
20
30
40
50

FIG. 14.

with heavy dashes represents the upper end of the run-curve corresponding to the portion of run, $O\ A$, and in the lower part of the diagram, the heavy line, D, represents the corresponding interpolated distance curve. The process of determining the terminal point A at which this portion of the curve should be cut off, is simple. The length of the portion $O\ A$ being 0.306 mile, according to Table II., a horizontal line e-f, is to be drawn in pencil on the tracing sheet at a point equal to this distance, when measured by reference to the distance scale at the point f, at the right-hand end of the diagram. This line is prolonged to the left until it intersects the distance curve D, at the point d. A vertical line ($d\ A$) is then drawn in pencil at this point until it meets the run-curve at the point A, which will be the terminal point, or the point at which the portion of the curve $O\ A$ is to be cut off. The point A corresponds in this particular case to a speed of 52.6 m.p.h., as indicated on the diagram.

We will now proceed to plot the second portion ($A\ B$) of the run-curve, which, according to Table II., is 0.113 mile in length, on an up-grade of 0.283 %,and has a track curve of 1° 30′, the net equivalent grade, including correction for track curvature, being + 0.351% (Column VII.). Without disturbing the tracing sheet, a portion of acceleration curve, corresponding to the portion of run $A\ B$, is to be plotted and drawn on the sheet. This portion of run-curve will obviously begin at some point on the horizontal dotted speed line passing through the terminal point A of the portion $O\ A$. If the " equivalent " grade (Column VII.) were, for example,—1.75%, the curve would begin at the point A'' and would have the form represented by the heavy full line $A''\ B''$. If the equivalent grade were − 0.75%, the curve would begin at the point A' and it would extend to the point B'. For the actual equivalent grade (+ 0.351%), the curve will begin at A and will run to B, being located about 0.7 of the distance between the curves for 0% and + 0.5%, so that it passes slightly to the right of the continuation of the previous curve (shown in dotted line).

To determine the length of the second portion ($A\ B$), we first drop a vertical line ($A\ d'$) from the beginning of this portion as far as the corresponding interpolation point (d') in the portion of the chart giving the distance curves. If this portion of run-curve were on a − 0.75% grade, beginning at A', the proper " interpolation " point in the distance curve would be at a', while if the curve were on a − 1.75% grade, beginning at A'', the proper in-

terpolation point would be at a''. Wherever this point may fall, the procedure will be the same; a horizontal line is to be drawn on the tracing sheet, in pencil, at a distance which, measured by the distance scale, at the right-hand end of the diagram, represents the length of the portion of run $A\ B$, namely, 0.113 mile, as given in Table II. On this line the terminal interpolation point (b_1) is located. The interpolated distance curve (D') itself may then be drawn, if desired, although that is scarcely necessary, it being sufficient to have the terminal point clearly indicated by a dot, such as shown at b'' and b'. A vertical line drawn from the terminal point to meet the interpolated acceleration curve will cut the curve at the proper time point. If drawn from the point b'' this line would cut the curve $A''\ B''$ at B''; if drawn from b' it would cut the curve $A'\ B'$ at B'; in the actual case, the proper line is the line b_1B which cuts the curve $A\ B$ at the point B (55.2 m.p.h.). The acceleration curves $B'\ B''$ have been purposely added to the diagram, in this case, to show graphically the important effect produced on the form of the acceleration curve by variations in grade. These curves show graphically the fact that the rate of acceleration increases greatly with the percentage of down-grade, the direct effect of this, of course, being that the speed attained at the end of the corresponding portion of the run is very much higher on down-grades of higher percentage, as clearly shown by the relative positions of the terminal points, B, B', B''.

In the third portion of run, $B\ E$, it becomes necessary to anticipate, and to make allowance for, the track curve of short radius, which occurs in the fourth portion ($C\ H$). The speed at the end of the portion $B\ E$, or the beginning of the portion $E\ H$, is, as previously stated, set at 25 m.p.h. This is, therefore, a case in which we must plot in both directions—" forward " from the point B, and " backward " from the point E. The portion B-C-E will have three " component " curves, including an acceleration portion, $B\ C$, a drifting portion, $C\ D$, and a braking portion, $D\ E$. The real problem in this case is the determination of the points C, D, at which the drifting curve $C\ D$ will begin and end. This has to be done largely by a " cut-and-try " process. We begin by plotting an acceleration curve for a net grade of $+0.283\%$, starting from the speed point B, (55.2 m.p.h.) and making the curve arbitrarily of some convenient length, such as may be thought suitable for the purpose. A vertical line (B-b_3) is dropped from the beginning of the portion $B\ C$ to the proper

interpolation point for the corresponding distance curve D''. Near the end of the portion plotted, a certain number of vertical lines (c', c'', c''', etc.) are dropped from the acceleration curve to the distance curve, and the distances corresponding to each of these vertical lines having been noted by reference to the distance scale, it is recorded in pencil opposite the letter or symbol representing each line, as indicated in the upper right-hand portion in Fig. 14. Thus, in Fig. 14, the distance covered, when the curve $B\,C$ is cut off by the vertical line, c, would be 0.67 mile. The corresponding distances, when the curve is cut off by the vertical lines, c', c'', c''', etc., would be, respectively, 0.071, 0.075, 0.070 mile, etc., each successive line representing a " slice " whose area represents a distance of 0.004 mile. The number of such vertical lines, and their distance apart, may, of course, be varied as desired, and as may seem best in each particular case.

The next step is to lay out a braking curve, working backward from the point E. This case is analogous to the upper portions ($F\,G$ and $G\,H$) of the braking curve in Fig. 12, and, consequently, will correspond with either problem 2 or problem 3 in Appendix D, according to the term which is made the unknown quantity. It will correspond to problem 2 when the distance covered, s, is given, and the entering speed (at the point D), is the unknown quantity to be determined. It will correspond to problem 3 when the entering speed is assumed, and the distance covered, s, is the unknown quantity to be determined. It may be necessary to try both ways, assuming a given value for the distance in the first case, and for the entering speed in the second case. A few preliminary calculations made both ways, based upon different assumptions, will enable a rough approximation to be made, both as to the distance covered and the entering speed, for the braking portion of the curve.

The next step is to plot, on a separate tracing sheet placed upon the chart of retardations (Fig. 8), a portion of drifting curve corresponding to the net equivalent grade ($+\ 0.283\%$) indicated in Table II., and of such length as may seem proper to form a connecting link between the points C and D, allowing extra length at both ends. The corresponding distance curve is to be drawn, by interpolation, on the same sheet. This sheet is then superposed upon the tracing sheet containing the acceleration portions. Let us assume that it has been superposed in such manner that the upper end of the drifting curve crosses the continuation of the acceleration curve, $B\,C$ (in Fig. 14), at a point corresponding to

the vertical line, c'''. If preliminary calculations have been made for the braking curve in the manner previously indicated, the distance covered while braking, as obtained from these calculations, should be added to the distance covered during the acceleration portion $B\,C\,c'''$, which, as indicated in Fig. 14, is 0.079 mile. The sum of the two distances corresponding to the braking and accelerating portions, subtracted from the total distance of the portion $B\,E$, namely, 0.374 mile, will give the distance remaining for the drifting curve ($C\,D$). If this calculated distance is greater than the distance indicated by the distance curve corresponding to the portion of drifting curves comprised between the vertical line, c''', and the vertical line corresponding to the assumed entering speed, D, it is an indication that this assumed value for the entering speed, D, is too high, or that the acceleration curve has been cut off too soon; and *vice versa*. We may first try the effect of changing the entering speed, D, and of locating it at different points along the drifting curve. In this case, the entering speed, D, being now known, we have a case corresponding with problem 3 (Appendix D), and the distance covered is to be determined by reference to equation (i). The effect of changing the point D, however, is to also change the distance covered by the drifting curve. It may, therefore, be necessary to change the relation of the drifting curve to the acceleration curve, so as to change the point of intersection between these two curves. In many cases, the distance allowed for braking can be fixed, and, consequently, the entering speed, D, can be calculated as a case of problem 2 in Appendix D, by means of Formula (l). This being done, the lower speed point of the drifting curve will also become fixed, and it will now be possible to make sub-divisions at the upper portion of the drifting curve similar to those made on the acceleration curve in Fig. 14, by the vertical lines, c, c', c'', c''', etc., the distance corresponding to each line being recorded in pencil on the tracing sheet. When this can be done, the process of finding the point C becomes greatly simplified. For each position of the drifting curve, with respect to the acceleration curve, the distance values corresponding to the two component curves can be readily calculated. If the sum of the two distances is too small, the two curves must be moved farther apart; if too large, they must be brought closer together. In the actual case, the proper point of intersection between the acceleration curve, $B\,C$, and the drifting curve. $C\,D$, takes place at the point C, corresponding to the vertical line $C\,c$,

representing a distance covered, under acceleration (Fig. 14), of .067 mile, the speed at the point C being 56.35 m.p.h. The drifting curve beginning at this point continues until the speed has fallen down to 53.2 m.p.h., the distance covered being 0.129 mile. (Fig. 13.) The braking curve represents a reduction of speed from 53.2 m.p.h. to 25 m.p.h., and a distance covered of 0.178 mile. The three component curves for this portion of the run aggregate exactly 0.374 mile, which is the distance given in Table II.

The fourth portion of the run ($E H$) also has three component curves, the first being an acceleration curve, which is to be plotted by interpolation, in the manner already described. It is cut off arbitrarily when it reaches the speed point of 35 m.p.h., that being, as already stated, the limit of speed for the track curvature occurring in this portion of the run. The distance covered is determined by the interpolated distance-curve, in the manner already indicated. A drifting curve for the portion $F G$ is then plotted, either on a separate sheet or by placing the same sheet over the Chart of Retardations. The length of this drifting curve may be varied arbitrarily. This being an express run, it is desirable to regain a higher speed with as little delay as possible when leaving the curve. It is usual to turn on the current and to let the train again accelerate in speed before passing entirely out of the curve, it being found practicable and safe to run out of a curve at a considerably higher speed than would be allowable at the beginning, or in the first portion of the curve. In this case the current was turned on after drifting down to a speed of 31.1 m.p.h. and at a point .041 mile from the end of the curve. The acceleration curve, $G H$, having been plotted by interpolation in the way already indicated, and having been cut off by means of the distance curve, at the point corresponding to the proper distance (.041 mile), the two succeeding portions, $H I$ and $I J$, could then be plotted without difficulty, either on the same sheet, or on separate sheets. On reaching the point J it becomes necessary again to anticipate for the final braking at the end of the run, and to plot both ways. The process to be followed in determining the point K is substantially the same as that followed for determining the point C, and need not be further detailed.

After all the " component " portions of the entire run curve have been determined they are to be assembled on one sheet. This can be done easily by tracing these portions on another tracing sheet, or the curves may be redrawn on a separate sheet,

after a certain number of coördinate points for each portion have been plotted on the sheet.

The curve *D D D* in Fig. 13 is the distance-curve obtained by integrating the service-run curve, *O A B C . . . . . N*. Its highest point corresponds, by reference to the scale of distance, exactly with the total length of the run (namely, 1.625 mile). The various bends in the curve are an indication of the irregularities in the service-run curve. The height of the curve at any time point, when gauged by the distance scale, measures the distance covered up to that time point.

Subsidiary Curves.—After the service-run curve has been plotted, it becomes possible to plot various other curves, which could not be plotted without it, and which, for this reason, are sometimes designated by the general term, "subsidiary curves." The complete discussion of these curves is beyond the scope of this paper, but some of the curves are so closely related to the service-run curve that a brief reference to them is really necessary, in order to give a general idea, at least, of some of the important uses which may be made of the service-run curve, in determining many of the important factors of a given electric railroad problem. The distance curve, *D D D*, just referred to, in Fig. 13, is an example of a "subsidiary curve." The most important of these curves are the electric power input curves, the current-input curves, and also the integral curves derived from them.

The power-input curve is a time-function curve, showing the instantaneous values of the energy applied to a train. This curve begins when the current is applied to the motors, and it ends when the current is cut off. Each acceleration cycle in the service-run curve, therefore, corresponds to and is characterized by a power input curve (and also an energy-input curve). Thus, in service run No. 7 (Fig. 12), in which, as already seen, there is only one acceleration cycle, there is only one power-input curve, which is indicated by a dotted line in the figure. On the other hand, in Fig. 13, where there are three acceleration cycles, there are also three power-input curves, which form the outlines of the three shaded areas in the figure.

The power-input curve and its integral curve, the energy-input curve, serve for the determination of many important factors, including the energy required for a given service, and also the size and character of power station necessary. The coördinate points for the power-input curve are calculated by reference to the "corrected" speed curve (*C*) on the sheet of motor charac-

teristics (Fig. 5). The current value, corresponding to each speed value, multiplied by the mean voltage available at the motor terminals, gives the power value in watts corresponding to that speed. In this way, the power values corresponding to all the speeds may be calculated. These values may also be plotted in the form of a power characteristic curve, in which speed and electric power (preferably expressed in kilowatts) are the coördinates. It should be borne in mind that when the series-parallel system of motor control is used, the energy applied to the motors, while the motors are connected in series, as is the case when running below a certain critical speed, will be, for a given current value per motor, only one-half as much as when the motors are connected in parallel. In the case of the two service runs shown in Figs. 12 and 13, the critical speed at which the change from series to parallel connection occurs, is 19.6 m.p.h. This circumstance accounts for the low portion of the power curve at the beginning, as indicated at P in Fig. 13. The voltage available at the motor terminals is not really applied to the motors themselves, as is well known, until the controller resistance has been entirely cut out. However, since, in reality, we desire to know the energy *applied to the train*, whether this energy be applied wholly to the motors themselves or whether it be partly expended in heating the controller resistance, the portion P is plotted just as if the energy were expended entirely in the motors. In this case each car is assumed to have a four-motor equipment, and the acceleration current, as previously stated, is assumed to have a mean value of 400 amps. per motor. The mean voltage is assumed to be 600 volts. At the time of starting, there being two pairs of motors connected in series per car, the power input will be:

$$600 \times 400 \times 2 = 480 \text{ kw.}$$

This is the ordinate value of the portion P of the power curve, as will be found by reference to the scale of kilowatts per car at the left-hand end of the diagram in Fig. 13.

After the resistance has been entirely cut out, the rate of acceleration would diminish, unless the controller is changed from the series to the parallel connection. This will be made clear by a comparison of the acceleration curves marked A and C in Fig. 11. The lower of the two curves marked A is substantially the same as the acceleration curve for level track (solid line) in Fig. 7. The lower curve marked C is the acceleration curve that would be obtained if the parallel connection were not used—that is to say, if

the acceleration were allowed to take place on the last step of the series connection, with the motors still connected in series, but with the controller resistance entirely cut out. (The upper curve in each case is that which corresponds to a higher gearing ratio than the gearing ratio used for the curves shown in Fig. 7.) When the change from series to parallel connection takes place, the total current per car will jump from 800 to 1600 amperes, and the power input curve also instantly jumps up to twice its value; it attains its highest point, Q, and there remains constant, as indicated by the straight line, until the controller resistance has again successively and entirely been cut out (when the speed has risen to 39.2 m.p.h.). It is at this moment that the acceleration begins to decrease (in accordance with the curves shown in Fig. 7, or with the curve A, shown in Fig. 11), because the counter e.m.f. due to the increase of speed, begins to reduce the current passing through the motors. The power applied to the car, therefore, begins to fall very rapidly, as indicated by the curved portion (R) of the power input curve in Fig. 13. The point (C) in Fig. 13 being, as we previously found, the point at which the acceleration ceases, it of necessity corresponds to the point at which the power is cut off; and the power curve suddenly drops down to zero at that point. In the second acceleration cycle, in Fig. 13, the speed (25 m.p.h.) at which the current is turned on, is higher than the "critical" speed; consequently, the motor controller must be in the parallel position, with only a part of the resistance cut out. As the whole of this resistance has not yet been cut off by the time the speed point F is reached, where the current is again turned off, it follows that the power curve (S) will be straight. In the power curve corresponding to the third acceleration cycle, the curve begins with a straight portion, but as the speed soon attains the point (39.2 m.p.h.) at which the controller resistance is all cut out, the power values again rapidly diminish same as in the first cycle, as indicated by the curved portion, U.

It should be noted that the portions, P, Q, S, T, will not, in actual practice, be absolutely straight lines. They will, in reality, be serrated or saw-shaped, with a number of humps or notches equal to the number of steps in the controller, or equal, rather, to the number of movements of the controller which the motorman makes during acceleration. These humps or notches are due to the fact that when the controller is moved from one step to the next, the current instantly jumps up to a higher value,

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and is then gradually reduced by the increase in e.m.f. due to the rising speed of the motor, the same process being repeated for each step or notch of the controller. With the Sprague multiple-unit system of control, it is possible to restrict, to some extent, the amount of fluctuation in current while the controller resistance is being cut out, so that the notches or teeth in the actual energy curve at the points P, Q, etc., will not be so large. This is due to the fact that the process of cutting out the controller resistance can, in this system, be made automatic, being controlled by the current passing through each motor. These current fluctuations theoretically react upon the acceleration, and tend to produce slight waves in the acceleration curves. Practically, however, their influence is negligible, being virtually obliterated by the inertia of the car.

Energy Curve.—If we integrate the area of each power or kilowatt curve, we obtain the value of the energy in kilowatt seconds (which, divided by 3600, gives the kilowatt hours), expended during the corresponding acceleration cycle. This is a valuable and useful quantity. If we integrate the power curve " by parts," we obtain the energy curve for each acceleration cycle. This has been done in Fig. 13, where the portions of curve, Ea, Eb, Ec, represent, respectively, the portions of energy input curve corresponding to the three acceleration cycles. The horizontal portions between the inclined portions merely indicate the fact that the total energy remains stationary between the different cycles. The aggregate energy for the three cycles, when read by reference to the scale of kilowatt-hours per car at the right-hand end of the diagram, will be found to be 14.22 kilowatt-hours. The portion of the total energy corresponding to each cycle may, likewise, be read separately by reference to the same scale.

Energy Consumption.—Having obtained from the energy curve the energy consumption during the run, and the weight of train and length of run being both known, the energy required in watt-hours per car-mile, or per ton-mile, may be easily calculated. The resulting data are given in Fig. 12 and Fig. 13. It will be seen that while, in Fig. 13, the energy consumption is only 114 watt-hours per ton mile, it rises, in Fig. 14, to 168 watt-hours per ton-mile, notwithstanding the fact that run No. 11 is shorter than run No. 7. This is, of course, due entirely to the presence of the sharp curve in run No. 11, which necessitates reduction of speed and subsequent accelerations, as already indicated.

Current-Input Curve.—The current-input curve is obviously of exactly the same form as the power-input curve, its ordinate values being different from those of the power curve by a constant equal to the mean voltage assumed in computing the ordinates of the power curve. The current curve may, therefore, be derived from the power curve, or the power curve itself may be used, as if it were the current curve, with a different scale of ordinates. The current curve is useful in calculations regarding the feeder and distributing systems necessary for transmitting electrical energy to the car motors. It is also useful in determining the losses to be expected in the conductors as well as in determining the heating of the motors. For the latter purpose the current input curve should be integrated twice successively. The first integration gives ampere seconds (coulombs) from which (dividing by 3600) we get "ampere hours." From the second integration the value of the *mean square* can be obtained; the square root of this value will be the equivalent heating current for the run. The work of integration will be greatly simplified by the use of an integraph or of a so-called mechanical integrator. The well-known, highly ingenious "Amsler mechanical integrator" has been found by the writer to be very convenient and satisfactory for this purpose. While it does not draw the integral curves, like the integraph, it has the advantage over the integraph, in this case, of giving at one single operation the results of both integrations, namely, the current-time integral or the coulombs $(a\int y\,dx)$ and the current-square time integral $(b\int y^2\,dx)$, and even a third integration $(c\int y^3\,dx)$ if desired. A detailed description of the modus operandi is beyond the limits of this paper.

Intrinsic Power Curves.—These curves show the instantaneous values of the power actually utilized in maintaining the speed during the entire run. The formulæ usually employed for calculating these power values give the result in mechanical horse-power. It is preferable, however, to convert the horse-power values into equivalent kilowatt values. The curve showing the instantaneous power values has been called the "intrinsic power curve." The integral of this curve would be another curve called the intrinsic energy curve. When the intrinsic energy curve and the energy-input curve are both drawn to the same scale the ratio of final ordinates of the intrinsic energy curve to the energy-input

curve, will represent the mechanical efficiency attained during the run.

The intrinsic power and energy curves are of interest and of utility in the minute analysis of railway problems.

APPENDIX A.

(Analytical Definitions.)

Time-Function Curves of Rectilinear Motion.

Motion and Velocity.—The phenomenon of motion being the natural starting-point in the analytical study of the speed-time curve, we may begin by noting some of its characteristics.

According to the definition given by the late Prof. S. W. Holman, in his able work on "Matter, Energy, Force and Work" (page 12), "*Motion is change of relative position.*" It is symbolized by *distance* and may be estimated and measured by reference either to its *amount* or to its *rate*.

The *amount of motion* of a body is equal to the length of the line (called "path") along which the motion takes place.

The *rate of motion* of a body is the proportional amount of its motion estimated by reference to some basis or unit of comparison. Time being the most convenient and practicable basis of comparison or proportion, the rate of motion, when estimated with reference to time, is equal to the change in amount of motion (or the variation of distance, or space) occurring in a definite interval of time, and it is then called the *time* rate of motion or the *time* rate of speed variation. Thus, when distance is expressed in miles, and time values in hours, the rate of motion will be equal to the quotient of the distance divided by the time consumed in moving over the given distance. In this case the quotient would be "miles per hour," which is the numerical measure of speed or velocity. Hence, *velocity is equal to the time-rate of motion*, or

$$v = \frac{ds}{dt} \qquad (a)$$

whose value would be:

$$v = \text{miles} \div \text{hours} = \text{miles per hour}$$

where

v = instantaneous velocity or speed (m.p.h.)
s = distance (space)
t = time (seconds)

If in Fig. 15 the ordinates be used to represent amounts of motion or distances, expressed, say, in feet, and if the abscissæ be used to represent time values, say, in seconds, then the curve O A B C D will represent the relation between any distance and the time required to pass over it by a moving body.

The amount of motion which has taken place between any two points, as A and B, on the curve, will be measured by the vertical distance dy $(= y' - y)$ between these two points. This amount of motion has taken place in the space of time dx $(= x' - x)$,

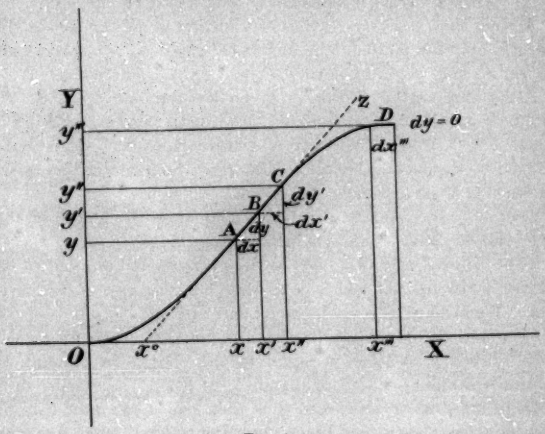


FIG. 15.

comprised between the two time intervals x and x'. Hence the amount of motion in unit time (*i. e.*, the time-rate of motion), or the velocity, will be

$$\frac{y' - y}{x' - x} = \frac{dy}{dx} \quad = \text{feet per second.}$$

Let the (dotted) line, x° - - - z, be drawn tangent to the middle point of the portion of the curve comprised between the points A and B. Then, by similar triangles, we have

$$\frac{dy}{dx} = \frac{Bx'}{x^\circ x'} = \frac{y'}{(x' - x^\circ)} = \tan B\, x^\circ\, x'$$

A similar relation would obtain in the case of a line drawn tangent to any other point whatever of the curve. Hence, the

differential coefficient $dy \div dx$, or the tangent, at any point of the curve, is numerically equal to the time-rate of motion, or the *velocity*, at that point.

The precise numerical value of the differential coefficient, for any point of the curve, will depend upon the angularity of the tangent line (analogous to the line $x^\circ - - - z$) at that point. For an angle of 90°, corresponding to any portion of the curve having an exactly vertical direction, we have $dx = 0$, while $dy =$ a finite quantity, and consequently, the value of the tangent being infinity, (as is well known from trigonometry), we will have

$$\frac{dy}{dx} = \frac{dy}{0} = \tan 90^\circ = v = \text{infinity},$$

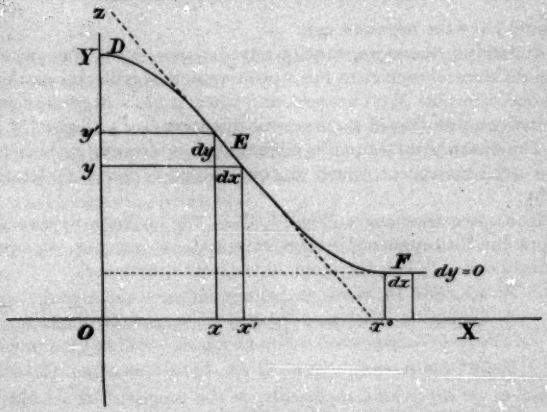


FIG. 16.

that is to say, the velocity will be infinite. For an angle of 0° corresponding to any portion (D) of the curve which is exactly horizontal, we have $dy = 0$, while $dx =$ a finite quantity, and, consequently, we will have

$$\frac{dy}{dx} = \frac{0}{dx} = \tan 0^\circ = v = \text{zero}$$

that is to say, zero velocity, *i. e.*, absolute rest.

A curve such as shown in Fig. 15 is, in reality, a "distance-time" curve, but is usually called, simply, a *distance curve*. From the preceding anaylsis, it will be readily seen that the slope of the curve or the angle which it makes with the axis of x, is an

indication and a measure of the velocity of the moving body. It is also an indication of the *direction* of motion, for, as will be seen, the elemental motion (dy) taking place in the time (dx) is *upward*, since the space increment (dy) when measured on the scale of ordinates, represents the progression from the point y to the point y'.

In Fig. 16 we have a distance time curve having a general downward slope. In this case, the elemental motion (dy), taking place in the elemental time (dx), is downward, since it represents the progression from the upper ordinate y' to the lower ordinate y. In such a case, the space increment (dy) would have a negative sign, and, consequently, the differential coefficient $\frac{dy}{dx}$ would have the negative sign.

It follows, therefore, that in any distance-time curve, when the differential coefficient has a positive sign, it indicates motion in one direction (*i. e.*) upward, and when it has a negative sign, it indicates motion in the contrary direction (*i. e.*) downward.

The distance-time curve is related in an interesting manner to the speed-time curve, which we now proceed to consider analytically.

In a speed-time curve (Figs. 1, 2, 3), the ordinate values (y) represent instantaneous values of speed, or velocity, as previously stated. We, therefore, have (from equation a),

$$y = \frac{ds}{dt} = v \qquad (b)$$

It follows that *the ordinates of a speed-time curve are proportional to the differential coefficients*, or the tangents, of a corresponding distance-time curve. Reciprocally, since integration is the reverse of differentiation: *Any distance-time curve may be regarded as the integral curve of a corresponding speed-time curve.* This is a very important and useful relation which may also be established in another manner.

The area (da) enclosed by any small portion of a speed-time curve corresponding to the time-element dt is

$$da = y\,dt$$

Substituting for y, according to equation (b), we have

$$da = \frac{ds\,dt}{dt} = ds \qquad (c)$$

or the elemental area of a speed-time curve is the equivalent of an elemental distance (ds). This elemental distance is equal to the difference in the ordinate values of a corresponding distance-time curve taken between the same time points.

The equivalent of ds, by equation (b), is

$$ds = v\,dt \qquad (d)$$

The integration of the speed-time curve between any two time points such as t^0 and t' will give

$$A = \int_{t^0}^{t'} v\,dt = s \qquad (e)$$

in which

A = the area of the portion of the speed-time curve comprised between the time values t^0 and t'.

and

s = the distance traversed in the interval of time t^0, t'.

By reversing the process, or differentiating, we return readily from equation (e) to equation (d), and thence to equation (b), which was our starting point.

The above relationship between the distance-time and the speed-time curves is utilized to advantage in plotting the "run" curves.

[This relationship was mentioned as early as 1885, by M. Bruno Abdank-Abakanowicz, in one of his serial articles on the "Integraph," published in *La Lumière Electrique* (Vol. XVIII, pp. 538-539), and reprinted in his work "Les Intégraphes," 1886, pp. 117-119.]

Variable Velocity and Acceleration.—Velocity, like motion itself, may be estimated by reference either to its *amount* or to its *rate*.

I. *Amount of Velocity.*—The *amount* of *velocity* (or the amount of speed) of a moving body, is the difference between two definite given velocities of said body. The two velocities by reference to which amount of velocity is determined, are sometimes called the "initial" and "final" states "of motion," or "velocities" of the body.

Equation (a) suggests at once the following analytic definition.

Amount of velocity is the difference between two given time-rates of motion of a body. In symbols we have, for the amount of velocity,

$$v'' = v' - v^\circ = \frac{ds'}{dt} - \frac{ds^\circ}{dt} \qquad (f)$$

where

v'' = amount of velocity
v° = initial velocity
v' = final velocity

When the initial velocity v° = zero, we have

$$v'' = v' \qquad (g)$$

In this case the amount of velocity is the *total* velocity. This is the quantity generally meant when we speak of a speed of so many miles or kilometres per hour, or so many feet or metres per second.

When the initial velocity is lower than the final velocity, equation (*f*) gives a positive value for v'', and we have a *gain* or *increase* in velocity, *which is acceleration*. The motion taking place under these conditions is called *accelerated motion*.

The following statements should be carefully noted:

Acceleration is increase in velocity.

It is measured in *miles per hour*, like velocity.

This is not the usual acceptation of the term acceleration, which, as we shall see later, is used, ordinarily, in a figurative sense, instead of "*time-rate of acceleration.*"

When the initial velocity is higher than the final velocity, then equation (*f*) gives a negative value for v'', and we then have a *loss* or *decrease* in velocity, which is *retardation*. The motion so conditioned is called *retarded motion*.

Retardation is decrease of velocity, and is measured in miles per hour, like velocity.

Since a loss or decrease is a negative gain or increase, it follows that retardation is, analytically, the same as *negative acceleration*; and it is in practice often designated by that term.

If the initial and final states of motion are exactly the same, equation (*f*) gives $v'' = 0$, and we have "*constant*" speed or velocity.

In the speed-time curve in Fig. 1, the points A, B, C correspond, respectively, to speeds of 55, 60 and 65 m.p.h. These figures represent the *total* velocity at the corresponding points. Reckoning from rest or zero velocity, there has been an increase in velocity, or an acceleration of 55 m.p.h. at the point A, of 60 m.p.h. at the point B and of 65 m.p.h. at the point C. The *gain in velocity*, or the *acceleration* between one point and the next, is equal to 5 m.p.h.

In Fig. 2, the points A, B, C, D correspond to speeds which are respectively 60, 50, 40 and 30 m.p.h. These figures represent the total velocity as before, but in this case the total velocity decreases from one point to the next, there being a *loss* of velocity or *retardation* of 10 m.p.h. between any one point and the next.

It will be noted that the time required to bring about the same acceleration or retardation is not the same between A and B, as between B and C. This shows that *acceleration* (using the term in the sense hereinabove defined), and *retardation*, are independent of time.

Between the points D and E, in Fig. 1, there is no gain or loss in velocity, or, in other words, there is no acceleration or retardation, the speed line being perfectly horizontal, thereby indicating *constant* or *uniform velocity*.

II. *Rate of Velocity.*—The rate of velocity which is most suitable for practical use is the *time-rate* of velocity, which is

$$\frac{dv}{dt}$$

where

$$v = \text{velocity}$$

and

$$t = \text{time}$$

We at once recognize this as being also the expression for the differential coefficient of a speed-time curve at any point.

Since, according to equation (*b*), the ordinate of a speed-time curve is already equal to a time-rate of motion, its differential coefficient, or the time rate of variation, at any point of the curve, will be equivalent to the second differential coefficient of a corresponding distance-time curve, or

$$\frac{dv}{dt} = d\frac{\left(\frac{ds}{dt}\right)}{dt} = \frac{d^2s}{dt^2} \qquad (g)$$

We see at once that while the differential coefficient of the distance-time curve $\left(\frac{ds}{dt}\right)$ indicated *amount* of velocity, the differential coefficient of the speed-time curve indicates *time-rate* of velocity. Since time-rate of velocity is equal to change in amount of speed (*or acceleration*) per unit time, it follows that it is equal to *time-rate of acceleration*. We therefore have

$$\frac{dv}{dt} = \frac{d^2s}{dt^2} = \text{time rate of acceleration.} \qquad (h)$$

for which the term "acceleration" is usually employed. The term "*rate of acceleration*" or "*acceleration rate*" would be more proper. The writer has sometimes used the term "*acceleration coefficient.*"

When acceleration is measured in miles per hour, as is usual in this country, we have

$$\frac{dv}{dt} = \frac{\text{Acceleration}}{\text{time}}$$

$$= \frac{\text{miles per hour}}{\text{seconds}}$$

$$= \text{miles per hour per second}$$

When $\frac{dv}{dt} = 0$, we have a horizontal speed line indicating zero acceleration.

When $\frac{dv}{dt} =$ a positive quantity, we have an upward slope in the curve, indicating increase in acceleration.

When $\frac{dv}{dt} =$ a negative quantity, we have a downward slope in the curve, indicating negative acceleration or retardation.

APPENDIX B.

Train Acceleration.

Derivation of Fundamental Formulæ.

The fundamental formulæ relating to Train Acceleration are derived directly from the formulæ for mechanical energy and mechanical work.

The mechanical work done by a source of energy in moving a body over a given distance is a measure of the mechanical energy usefully expended in doing this work, and it is equal to the product of the propelling force acting against the body by the distance over which the body has travelled, or

$$E = Fs \qquad (1)$$

from which we have

$$F = \frac{E}{s} \qquad (1a)$$

where

E = Energy (or work)

F = Force exerted (in causing pressure, push or pull)
s = Distance travelled.

The above (1) is the equation of *potential energy*. When considering the changes of energy in a *moving* body, especially where the force exerted does not remain constant, the equation may be modified so as to estimate separately the energy for each small element (ds) of the distance travelled, thus:

$$dE = F\,ds \tag{2}$$

the total energy corresponding to the whole distance being, in that case,

$$E = \int_0^s F\,ds$$

The distance factor of the energy developed may be expressed in terms of the velocity of the body at each instant of time. Velocity being, itself, a time-rate of space variation, we have

$$v = \frac{ds}{dt} \tag{3}$$

whence

$$v\,dt = ds \tag{3a}$$

where

v = velocity
t = time

Substituting this value of ds in equation (2) we have

$$dE = F\,v\,dt$$

which expresses the change in the mechanical energy imparted to a moving body at each instant of time. We also have

$$\frac{dE}{dt} = F\,v \tag{4}$$

or, " the time-rate of variation of energy is equal to the product of force by velocity."

The kinetic energy of a moving body, according to the well-known formula, is

$$E = \frac{M\,v^2}{2} \tag{5}$$

in which M = the mass of the moving body.

Differentiating with respect to v, we have

$$dE = M\,v\,dv$$

which expresses the change in the mechanical energy imparted to a moving body at each change of speed. Dividing by dt (*i.e.*, differentiating with respect to time, and taking the derivative), we have

$$\frac{dE}{dt} = M\,v\,\frac{dv}{dt} \tag{6}$$

which is another expression for the time-rate of variation of energy.

Equating (4) and (6), we have

$$F\,v = M\,v\,\frac{dv}{dt}$$

whence

$$F = M\,\frac{dv}{dt} \tag{7}$$

but $dv \div dt$ is the time-rate of change of velocity, *which is rate of acceleration.* [This can be readily seen from equation (3); by differentiating with respect to time (t) we have the second derivative

$$\frac{dv}{dt} = \frac{d^2s}{dt^2}$$

which is the same as equations (g) and (h), in Appendix A.]

Hence, if we designate this time-rate by the symbol A, we obtain the well-known fundamental equation

$$F = M\,A \tag{8}$$

which states that "*force is equal to the product of mass by rate of acceleration*"; from which we derive

$$A = \frac{F}{M} \tag{9}$$

This equation, which expresses the relation between the acceleration produced in a given mass and the force acting upon it, is the fundamental equation for acceleration. The formula requires modification in order to make it convenient for practical use. The mass (M) should be expressed in terms of weight. The rate of acceleration (A) should be based on increments of velocity, stated in miles per hour, and the force (F) should be expressed as a pull in pounds per ton.

The force of acceleration is usually estimated in "gravity-

measure," that is to say, by reference to the acceleration produced in a falling body by the action of gravity.

The distance travelled by a falling body is

$$s = \frac{gt^2}{2} \tag{10}$$

where

g = the acceleration constant due to gravity
t = time (in seconds)
s = distance travelled (in feet)

The velocity of the falling body is

$$\frac{ds}{dt} = gt = v \tag{11}$$

and its rate of acceleration is

$$\frac{d^2s}{dt^2} = g = \frac{dv}{dt} \tag{12}$$

The force exerted by gravity is, by equation (8),

$$F = M\,A \tag{12a}$$

When a body falls and reaches the end of its fall, its potential energy is all converted into kinetic energy. The equation (1) for potential energy may be written

$$E = s\,w = \text{ft. lbs.}$$

when the force w is expressed in pounds, and the distance s is expressed in feet.

Using equation (5) for the kinetic energy, and equating the two, we have

$$E = \frac{M\,v^2}{2} = w\,s \tag{13}$$

Substituting for s its value as given in equation (10), the preceding equation becomes

$$\frac{M\,v^2}{2} = \frac{w\,g\,t^2}{2} \tag{14}$$

whence

$$M\,v^2 = w\,g\,t^2$$

Taking the value of v ($= g\,t$), and substituting for v its value as given in equation (11), the above equation becomes

$$M\,g^2\,t^2 = w\,g\,t^2$$

which reduces to

$$M\,g = w \tag{15}$$

whence we have

$$M = \frac{w}{g} \tag{16}$$

The value of g may be taken as

$$g = 32.2$$

so that mass expressed in gravity measure is equivalent to weight in pounds, divided by 32.2; or, we have

$$M = \frac{w}{g} = \frac{w}{32.2} \tag{17}$$

when w is expressed in pounds.

If we substitute this value for M in the fundamental equation (9) for acceleration, we have

$$A = \frac{F}{\frac{w}{32.2}} \tag{18}$$

or

$$A = \frac{32.2\,F}{w} \tag{18a}$$

F being, according to equation (1a), the ratio of the energy to the distance travelled, that is, the pulling force exerted over said distance. This pulling force is expressed in pounds, and when speeds are expressed in feet per second, energy (E) is expressed in foot-pounds and distance (s) is expressed in feet.. The above formula (18a), therefore, expresses acceleration as a gain or loss in speed measured in feet per second, obtained during one second, that is to say, the increase or decrease in velocity in feet per second PER SECOND. In dealing practically with train acceleration, the speeds are usually estimated in miles per hour, and the gain in speed per second is, as a rule, expressed as the increase or decrease in miles per hour, PER SECOND. The formula (18a), therefore, requires to be modified by a conversion factor expressing the relation between an acceleration of a foot per second per second and a mile per hour per second. Since a mile is equal

to 5,280 feet, and an hour is equal to $60 \times 60 = 3{,}600$ seconds, it follows that a velocity of one mile per hour $= \frac{5{,}280}{3{,}600}$ $= 1.467$ feet per second. Using the letter "A" to indicate acceleration in feet per second per second (as in formula (18), and the letter a to indicate acceleration in miles per hour per second, we have the following equation:

$$A = 1{,}467a$$

whence

$$a = \frac{A}{1{,}467}$$

or

$$a = .682A \tag{19}$$

which means that an acceleration of one foot per second PER SECOND is equal to an acceleration of .682 mile per hour PER SECOND.

Therefore, substituting the value of A, as given in equation (18), we have

$$a = .682 \times 32.2 \times \frac{F}{w} \tag{20}$$

in which the numerical value of a is equal to the gain or loss of speed (in miles per hour) per second. If the weight (w) is to be expressed in tons of 2,000 pounds, as is the general practice in this country, we must substitute its value such that

$$w = 2{,}000\,W$$

where

W = tons (of 2,000 pounds)

and where

w = pounds (lbs.)

This means, simply, that the symbol (W) representing weights IN TONS must be multiplied by 2,000 to give the equivalent weight IN POUNDS. Substituting for w its value, in terms of W, the equation for acceleration (20) becomes

$$a = \frac{d^2s}{dt^2} = \frac{(0.682 \times 32.2)F}{2{,}000\,W}$$

$$= \frac{21.96\,F}{2{,}000\,W} \tag{21}$$

$$= \frac{.01098\,F}{W} \tag{21a}$$

Solving for F, we have

$$F = \frac{W\,a}{.01098}$$

$$= 91.1\,W\,a \qquad (22)$$

If we are considering the force (F) corresponding to unit weight ($W = 1$ ton), and unit acceleration ($a = 1$ mile per hour per second), the preceding equation reduces to

$$F = 91.1$$

This means that an effort or pull of 91.1 lbs. is required for each ton of train weight for maintaining acceleration at the rate of one mile per hour per second.

Solving for W, we have

$$W = \frac{.01098\,F}{a} \qquad (23)$$

These three equations (21), (22), (23), give the value of each of the three quantities a, F and W, when the other two are known or assumed. They are the formulæ usually employed in discussing problems in train acceleration. The term F, it should be carefully noted, does not symbolize the TOTAL force applied to, or absorbed by, the train, but only that part of it which is expended in producing acceleration. It is one of the two factors of that portion of the total energy applied to the train which is really *stored* in the train in the form of kinetic energy of momentum; the other factor being (according to the fundamental formula of work, hereinabove), the distance traversed while the force is operating. If the force remain constant in value throughout the entire distance, we have

$E = F\,s$, which is the same as equation (1).

If the force varies at different points, we have

$E = \int F\,ds$, which is the same as equation (2)

In any case where there are other forces besides that which is expended in, and represented by, the production of acceleration, these other forces may also be expressed in *terms of acceleration*, and using the letters F' F'' F''' to represent these forces, the *total* force P, would be:

$$P = F \pm F' \pm F'' \pm F''' \pm \text{etc.} \qquad (24)$$

the sign ($\pm$) being taken to mean that the forces in question may be either such as to produce acceleration, or such as to prevent it. The acceleration (a) which each of these forces would produce by itself, is to be determined by reference to equation (21a) same as the acceleration corresponding to stored energy.

Using the symbols a', a'', a''' to indicate these accelerations, and substituting their value, as given by equation (21a) in equation (24), we have

$$P = 91.1\,W\,a \pm 91.1\,W\,a' \pm 91.1\,W\,a'' \pm 91.1\,W\,a''' \pm \text{etc} \tag{25}$$

Since 91.1 W is common to all these terms, we may write this equation as follows:

$$P = 91.1\,W\,(a \pm a' \pm a'' \pm a''' \pm \text{etc.}) \tag{25a}$$

From this equation we have

$$\frac{P}{91.1\,W} = a \pm a' \pm a'' \pm a''' \pm \text{etc.} \tag{26}$$

But P being the total force, according to equation (25), and the quantity, 91.1 W, being the "converted" measure of mass the quotient of these two quantities represents, according to equation (9) an acceleration which might be called the *total acceleration*. Using the symbol A' to designate this total acceleration, we have

$$A' = 91.1\,\frac{P}{W} = a \pm a' \pm a'' \pm a''' \pm \text{etc.} \tag{27}$$

or the effective acceleration, in any concrete case, is equal to the algebraical sum of the accelerations which would be produced by each of the forces acting independently and alone.

This is a most important deduction which is of great utility and convenience in simplifying the analysis and the plotting of speed-time curves.

Equation (27) may be put in more practical form. The symbols "a" used in this equation in reality represent time-rates of acceleration, as is fully explained in Appendix A; consequently, each one is equal to a time-rate of velocity, ($dv \div dt$). The equation may, therefore, be written

$$A' = \frac{dv}{dt} = \frac{dv'}{dt} \pm \frac{dv''}{dt} \pm \frac{dv'''}{dt} \pm \text{etc.} \tag{28}$$

The analytical statement of the deduction previously noted is, therefore, as follows:

The differential coefficient of an acceleration curve is equal to the algebraical sum of the individual differential coefficients corresponding to the various forces concerned and operating in producing the acceleration, each of these differential coefficients being determined separately just as if it were alone concerned in the result.

Using the letter " k " (as is done in Appendix C), as a symbol to designate a time-rate of velocity, the above equation becomes:

$$A' = k \pm k' \pm k'' \pm \text{etc.} \qquad (29)$$

where k, k', k'', etc., represent the values of the differential coefficient, corresponding to the accelerations a, a', a'', etc., in equation (27).

APPENDIX C.

Formula for Time-Values of Speed-Time Curves

The most convenient and practical way of drawing a speed-time curve is to locate or " plot " on a sheet of paper, the coördinates for a certain number of points of the curve, sufficiently close together for the purpose, and to then draw a line passing through or near these points. The more precisely these points have been determined and plotted, and the more numerous they are, the more perfect will be the curve, and the fewer the points which are, so to speak, out of line of the " mean path " through the aggregation of the coördinate points.

The data of each case furnish the necessary information regarding the *speed*, which is the ordinate value for each coördinate point of the curve; but they give no direct information about the *time value* corresponding to each speed value, that is to say, about the horizontal distance of the next ordinate, either from the starting point, or from the last point plotted. Fortunately, the data either give or furnish the information necessary to obtain the value of the differential coefficient, or the time-rate of speed variation, which corresponds to each speed value, and which determines the inclination or slope of the curve at that particular speed point. Taking advantage of this circumstance, a formula for pre-determining the time values corresponding to the speed-values, may be obtained by the solution of a simple geometrical problem. This problem may be stated as follows:

"Given the ordinate (y) and the differential coefficient ($dy \div dx$) at any point of a curve to find the abscissa (x) corresponding to said ordinate, or the distance of said ordinate from the axis of ordinates (OY).

There are two cases:

First.—Curves having a positive differential coefficient, or an *upward* slope.

These curves are generally concave to the axis of x.

This case includes all *accceleration curves*.

Second.—Curves having a negative differential coefficient, or a *downward* slope.

These curves are generally convex to the axis of x.

This case includes all *retardation curves*.

First Case.—(Fig. 17). Let dotted lines a - b, c - d, e - f, be drawn tangent to the curve $O\,E\,F$ at various points. Let the

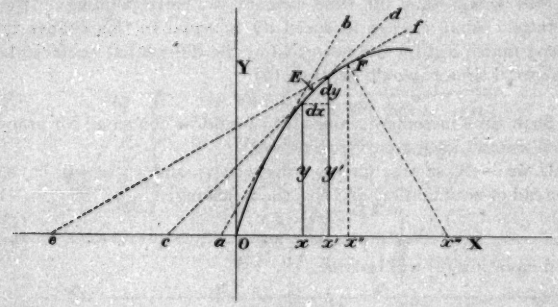


FIG. 17.

vertical lines, y and y', be ordinates which are very close together and correspond to the point of tangency (E). The time space or difference (dx) between these ordinates, or

$$dx = x' - x \qquad (a)$$

and the difference between the ordinates, or the speed increment

$$dy = y' - y \qquad (b)$$

are both assumed to be infinitely small.

By similar triangles, we have

$$\frac{y}{cx} = \frac{dy}{dx} \qquad (c)$$

Or the ordinate (y) at the point of tangency, divided by the "sub-tangent" (cx) is equal to the differential coefficient for

the said point. The numerical value (k) of this differential coefficient is known, or can be calculated from the data of the case, so that we have

$$\frac{dy}{dx} = k$$

whence

$$dx = \frac{dy}{k} \qquad (d)$$

It should be noted that dx is really the subtangent of the small or differential triangle $E\,dy\,dx$.

Equation (d) may also be written

$$dx = dy \times \frac{1}{k} \qquad (e)$$

This means that the time element dx, corresponding to the infinitely small change in speed dy, is equal to this change in speed multiplied by the *reciprocal* of the differential coefficient. The total time x' would be, from (a)

$$x' = x + dx \qquad (f)$$

Such time increment values (dx) would be too small for practical use in plotting curves, however.

If we increase the difference between x and x', we will have, instead of equation (a) and (b), the following:

$$x' - x = \Delta x \qquad (g)$$

$$y' - y = \Delta y \qquad (h)$$

and equation (c) will become

$$\Delta x = \Delta y \times \frac{1}{k} \qquad (i)$$

while equation (f) will become

$$x' = x + \Delta x \qquad (ii)$$

when Δy = the speed increment corresponding to the time increment Δx.

An important question arises in this case, however. So long as the time difference was very small ($= dx$), and the ordinates y and y' remained very close to each other, the differential coefficient had substantially the same numerical value (k) at the ordinate y as at the ordinate y', and no substantial error would result from taking either of the two values of this coefficient.

When the time distance is increased (to Δx), however, the differential coefficients at the two ordinates y and y' may be

materially different. This is illustrated in Fig. 18, where the conditions are purposely exaggerated. In this case we have

$$\frac{dy}{dx} = \frac{y}{cx} = k \tag{j}$$

at the point E, and

$$\frac{dy'}{dx'} = \frac{y'}{ex'} = k' \tag{k}$$

at the point F,

the two being evidently different in value, and one being evidently larger, the other smaller, than the differential coefficient corresponding to some intermediate point of the curve such as D, between E and F. If we draw the line g, h, parallel to the tangent line g', h', we have the differential triangle E F H, exactly similar to the differential triangle corresponding to the point D, and we

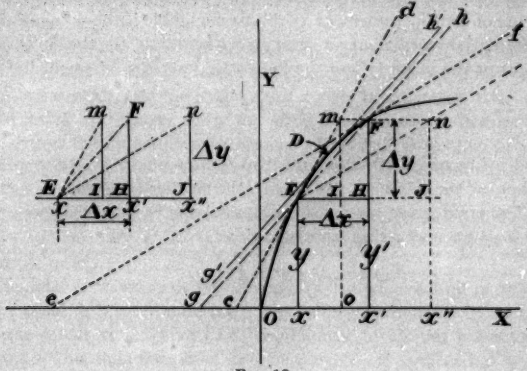


FIG. 18.

can write

$$\frac{dy^\circ}{dx^\circ} = \frac{\Delta y}{\Delta x} = k^\circ \tag{l}$$

where y°, x° (not shown in the diagram), are the coördinates of the point D, and k° = the differential coefficient thereof.

The differential triangles E m I and E n J correspond, respectively, to the coördinates of the points E and F and to their differential coefficients, k and k', as defined in equations (j) and (k). These two differential triangles and the differential triangle $E\ F\ H$ are reproduced by themselves in the left-hand portion of Fig. 18.

As pointed out in connection with equation (*d*) the subtangent of the differential triangle is the time increment (Δx) in each case. Hence, the three triangles show graphically the different values of Δx obtained by equation (*i*) when, with the same value of Δy, the different values of the differential coefficients (k, k°, k') corresponding to the points E, D and F, are used.

It is seen that the intermediate coefficient value k° is the one giving the correct time increment value (Δx). The lower value, k, makes the time increment too small by the distance I H; while the higher value, k', makes it too large by the distance H J. The point D is approximately midway between the points E and F. If the curve had a constant rate of curvature, like the arc of a circle, the point D would be exactly midway; it would be shifted to the left if the rate of curvature is decreasing, and to the right if the rate of curvature is increasing. In practice the error in the value of time increment (Δx) will be negligible if the value of the differential coefficient is that corresponding to the midway point or the mean (y'') of the two speed values y, y', such that

$$y'' = \frac{y + y'}{2}$$

and, of course, the nearer the two values y and y' are to each other (or the smaller Δy is taken), the smaller the error.

The error made may easily be calculated. If we designate it by $\Delta x^\pm$ we may write, from equation (*i*)

$$\begin{aligned} \Delta x^\pm &= \Delta x' - \Delta x'' \\ &= \frac{\Delta y}{k'} - \frac{\Delta y}{k''} \\ &= \Delta y \left(\frac{1}{k'} - \frac{1}{k''} \right) \\ &= \Delta y \left(\frac{k'' - k'}{k'\, k''} \right) \end{aligned} \qquad (m)$$

where

$\Delta x^\pm$ = amount or error,
$\Delta x''$ = the wrong value,
$\Delta x'$ = the correct value,

and the proportion of error would be,

$$\frac{\Delta x^\pm}{\Delta x'}$$

The above equation (m) in reality gives the difference in time value resulting from having assumed some greater or less value than the proper value (k') of the differential coefficient. If the value of k'' was taken too great (which is the case symbolized by the differential triangle E m 1), the factor $k'' - k'$, and consequently the value of $\Delta x^{\pm}$, representing the correction for error, will have the positive sign. On referring to the first line of equation (m) we see that $\Delta x^{\pm}$ can only have the *plus* sign when $\Delta x''$ or the "wrong" time value is *less* than $\Delta x'$, the correct time value. Hence, the plus sign will mean that the correction is to be made by adding the amount $\Delta x^{\pm}$, obtained by equation (m), to the "incorrect" time value ($\Delta x''$), previously obtained. If the value of k'' was taken too small (as in the case symbolized by the differential triangle E n J), the sign of $\Delta x^{\pm}$ will be *negative* showing that this amount, Δx, is to be subtracted from the incorrect amount, $\Delta x''$.

In practice, the speed differences (Δy) between any two successive points of the curve are expressed in miles per hour, or fractions thereof, and the time values Δx are taken in seconds.

Equation (m) shows that the error would increase in direct proportion with the speed increment (Δy), and in inverse proportion with the product of the reciprocals of the two differential coefficients considered.

(NOTE.—Usually k' and k'' have very nearly the same values, hence the product k', k'' is very nearly equal to the *square* of either k' or k'').

The *total* time value or the abscissa (x') corresponding to any speed point (y') is obtained, as indicated in equation (ii) by adding the latest time value (Δx) to the *sum* of all the previous values. This summation of previous values is symbolized by x in equation (ii).

Second Case.—(Fig. 19). The dotted line, c - d, being drawn tangent to the point E, we have, by similar triangles.

$$\frac{dy}{dx} = \frac{y}{xd} \qquad (cc)$$

just as in equation (c). In this case, however, we observe that the symbol dy represents a *diminution* of speed, because y is greater than y', and, consequently, if we applied equation (b) we would have

$$y' - y = -dy \qquad (n)$$

since $y = y' + dy$.

Hence, equation (*cc*) should be written

$$-\frac{dv}{dx} = -\frac{y}{xd} = -k \qquad (n)$$

and we have, by analogy to equation (*e*)

$$dx = -dy \times \frac{1}{k} \qquad (o)$$

and by analogy to equation (*i*),

$$\Delta x = -\Delta y \times \frac{1}{k} \qquad (p)$$

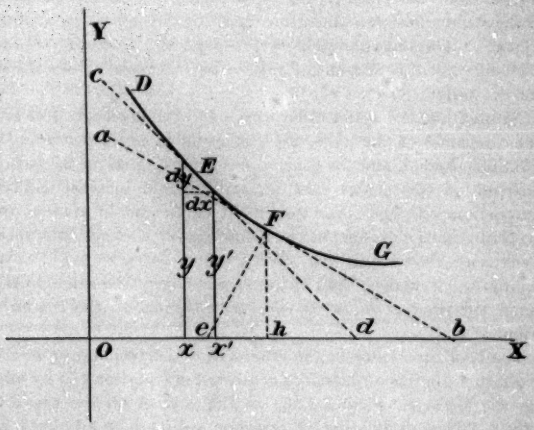


FIG. 19.

or the successive time increments, Δx, correspond to descending speed values ($-\Delta y$), in the curve.

In this case as in the first case, there will be an error, if the wrong differential coefficient is used in applying equation (*p*). This error has, however, a slightly different expression, resulting from the negative sign in (*p*).

Using the same notation as before, we have

$$\Delta x^{\pm} = \Delta x' - \Delta x''$$

$$= -\frac{\Delta y}{k}\left(-\frac{-\Delta y}{k''}\right)$$

$$= \frac{\Delta y}{k''} - \frac{\Delta y}{k'}$$

$$= \Delta y \left(\frac{k' - k''}{k'' \, k'} \right) \qquad (q)$$

In this case a positive sign for $\Delta x^{\pm}$ will mean that the incorrect value ($\Delta x''$) is too large, and must be reduced by an amount equal to $\Delta x^{\pm}$. Since the general form of equation (q) is the same as that of equation (1), the remarks already made concerning the proportionality of the error will also apply to this case.

The practical significance and application of the foregoing analysis and reasoning are as follows:

Accuracy in plotting speed-time curves requires that:

First.—The speed points should not be taken too far apart (or the speed differences should not be taken too great).

Second.—The " flatter " the curve (or the smaller the rate of acceleration), the smaller the speed differences ought to be.

Third.—For high accelerations (corresponding to the lower portions of acceleration curves), the speed differences may be taken from 1 mile per hour to 10 miles per hour, or even higher, according to the degree of precision required.

Fourth.—For low accelerations the speed differences must be gradually reduced as the rate of acceleration decreases (as in the flat parts of acceleration curves), until it amounts to a small fraction of a mile per hour—from five-tenths to one-tenth or less, according to the degree of precision required.

Fifth.—The speed increment (Δy) should be reduced whenever it gives by equation (i) a too high time increment value (Δx). The time value may be considered high when it exceeds two seconds for high accelerations, five seconds for medium accelerations, and ten seconds for low accelerations. For very accurate work, the limits ought to be set considerably lower, or one-half second for high accelerations, two seconds for medium accelerations, and five seconds for low accelerations.

These observations have been verified and confirmed by practical experience.

APPENDIX D.

Brake Curve Problems.

To plot any portion of a braking curve which follows or which is assumed to follow a straight line, we only need to determine the coördinates of the first and last points of the said portion of curve.

The three following "problems" show how the coördinates may be determined in different cases.

Problem 1.—At what speed point must the brakes be applied in order to bring the car to a stop at an exact given point, the rate of retardation being constant and known or assumed.

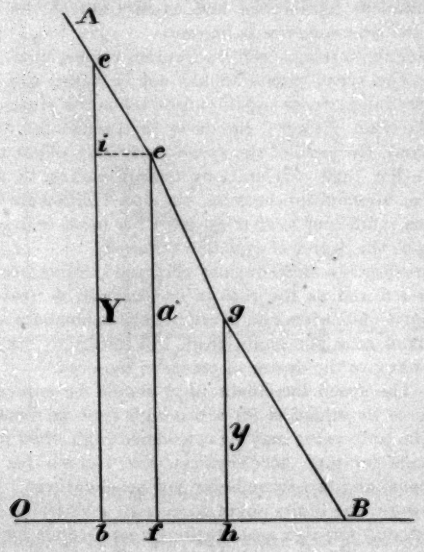


Fig. 20.

This problem is the same as that of finding the point g in Fig. 20.

Let ordinates (y) represent speeds (m.p.h.)

Let abscissæ (x) represent time (seconds)

Let s = distance, in miles.

Let A = area, (m.p.h. seconds).

It has been shown in Appendix A (Equation e), that the area

of any portion of a speed-time curve is equal to a distance.

In this case the rate of retardation being assumed constant, and the speed-line being consequently straight, the area of the portion considered ($h\ g\ B$), is the area of a right-angled triangle, which, it is well-known, is equal to

$$A = \frac{y\,x}{2} \qquad (a)$$

In this case the value of x is not given. We can obtain it however, from the rate of retardation

$$\frac{dy}{dx} = k$$

Since k is assumed constant, we may write $y \div x = k$ whence

$$x = \frac{y}{k} \qquad (b)$$

Substituting this value in (a) we have

$$A = \frac{y^2}{2\,k} \qquad (c)$$

The speeds being taken in miles per hour, and the time values in seconds, the area value will be expressed in m.p.h. seconds. A train moving with a velocity of one mile per hour for one hour would cover a distance of exactly one mile. There being 3,600 seconds in one hour, it follows that 3,600 mile-seconds *of area* are equivalent to one mile of *distance*. Hence, dividing the area A by 3,600, we have distance s in miles, or

$$s = \frac{A}{3{,}600} = \frac{y^2}{2\,k\,3{,}600} = \frac{y^2}{7{,}200\,k} \qquad (d)$$

from which, solving for y, we have

$$y^2 = 7{,}200\,k\,s$$

$$y = \sqrt{7{,}200\,k\,s} \qquad (e)$$

which is the speed point " g " in Fig. 20.

The time value (x) will be (from equation b),

$$x = \frac{y}{k} = \frac{\sqrt{7{,}200\,k\,s}}{k} \qquad (f)$$

Problem 2.—At what speed must braking begin in order to

travel a specific distance, and still have a certain definite speed, at the end of said distance, the rate of retardation being constant and known or assumed?

This problem may also be stated as follows:

Given the speed value (e) which a car must still have after having passed over a given distance while being braked, and under a constant given rate of retardation, to find the initial speed value (c) at which the braking must begin.

The area of the portion of curve under consideration (b, c, e, f), is equal to the mean of the ordinates multiplied by the abscissa, or

$$A = \frac{(Y+a)\,x}{2} = (Y+a)\,\frac{x}{2} \qquad (g)$$

The value of x is obtained, as in the previous problem by reference to the rate of retardation

$$\frac{dy}{dx} = k \qquad (h)$$

This equation, it is evident, applies only to the upper or triangular portion, $i\,c\,e$, of the whole area. Hence, the value of y, as given in equation (b) must be taken to mean, in this case, that portion of y' which is above the point i. This portion is

$$y = Y - a$$

which value, substituted for y in equation (b) gives

$$x = \frac{Y-a}{k} \qquad (i)$$

This value, substituted in equation (g) gives

$$A = \frac{(Y+a)\,(Y-a)}{2\,k}$$

$$= \frac{Y^2 - a^2}{2\,k} \qquad (j)$$

Dividing by 3,600, as before, we have

$$s = \frac{A}{3{,}600} = \frac{Y^2 - a^2}{7{,}200\,k} \qquad (k)$$

whence, solving for Y,

$$Y^2 = 7{,}200\,k\,s + a^2$$

$$Y = \sqrt{7{,}200\,k\,s + a^2} \qquad (l)$$

The value of Y is the speed at the point c in the curve.

Problem 3.—What will be the distance covered when braking for the purpose of reducing the speed from a given initial value to a given final value, the rate of retardation being constant and being known or assumed?

The solution of this problem is easily obtained by solving for s, in equation (l) of Problem 2. The solution gives:

$$s = \frac{V^2 - a^2}{7{,}200\ k} \qquad (m)$$

which is the same as equation (k).

(Note.—In all three of the preceding Problems, k is the resultant retardation, and its value is to be obtained according to the formula in equation (X) given in Section II of the paper.)

APPENDIX E.

Use of Metric System.

When the metric system of measurement is used, the formulæ and the methods of plotting mentioned in this paper will still apply if modified so as to make due allowance for the difference between the metric and English units employed for measuring distance, speed, and weight.

The usual practice, in all countries where the metric system is in use, is to measure train speed or car speed, (*i. e.*, "*amount* of velocity) in "kilometres per hour," a term of measure analogous to our term "miles per hour." The logical term or unit of measure for acceleration (*i. e.*, *rate* of velocity), or for the quantity termed the "acceleration coefficient" in the paper, would be "kilometres per hour" *per second*, which would be analogous to our term "miles per hour" *per second*. For some reason, however, this unit does not seem to be much used, if at all. The unit of acceleration generally used by European engineers is the "*metre per second per second*," which is analogous to our "foot per second per second." It certainly would be more logical and less confusing to express both *amount* and *rate* of velocity in like terms, using either *kilometres per hour* only, or *metres per second* only, for the *amount*, and the same unit *per second*, for the *rate* of velocity, (acceleration coefficient).

Train weights, according to the usual practice, when using the metric system, are expressed in metric tons (2,204.6 lbs.).

Time values are expressed in seconds, minutes or hours, just as in the English system.

The following table gives, for both systems, the corresponding

values of certain quantities which enter in the equations employed in the paper:

WEIGHT.

METRIC UNIT.		ENGLISH UNIT.
1 Kilogram	=	2.2046 lbs.
0.4536 kilogram	=	1.0 "
1 ton	=	1.1023 ton of 2000 lbs.
0.9072 ton	=	1.0 " " " "

DISTANCE.

1 metre	=	3.281 ft.
0.3048 metre	=	1.0 ft.
1 kilometre	=	3281 ft.
" "	=	0.6214 mile.
1.609 "	=	1.0 "

VELOCITY.

1 metre per second	=	3.281 ft. per second.
1 " " "	=	2.24 miles per hour.
1 " " "		
= .36 kilometres per hour.		
0.305 metre per second	=	1 ft. per second.
0.447 " " "	=	1 mile per hour.
1 kilometre per hour	=	0.621 mile per hour.

ACCELERATION.

1 meter per second per second = 1 "A" unit of acceleration.	=	2.24 m.p.h. per sec.
1 kilometre per hour per second = 1 "a" unit of acceleration.	=	0.621 m.p.h. per sec.
0.447 "A" unit	=	1.0 m.p.h. per sec.
1.609 "a" "	=	" " " "

1 "A" unit = 3.6 "a" units.
1 "a" " = 0.278 "A" "

We now proceed to investigate the effect of these changes in numerical value on the equations given in the paper.

Appendix A.—The same equations will all apply without change. If distance (s) is expressed in metres, and time in seconds, then velocity (v) will be expressed in " metres per second." If distance is expressed in " kilometres " and time in hours, velocity will be expressed in " kilometres per hour."

Appendix B.—Equations (1) to (16) will apply without change, the symbols v, s, g, w, being taken in suitable metric units. All the other equations require modification.

In Equation 1*a*, when energy (E) is expressed in kilogram-metres, and distance (s) is expressed in metres, force (F) will be measured in kilograms of (pushing or pulling) effort.

The metric value of g being taken as 9.81 (metres per second) and w being taken in kilograms, we will have for equation (17), and using the letter "m" as a distinguishing sign for "metric" equations,

$$M = \frac{w}{g} = \frac{w}{9.81} = .102\,w \qquad m(17)$$

and for equation (18a)

$$A = \frac{F}{.102w} = \frac{F}{w}9.81 \qquad m(18a)$$

the force, F, being expressed in *kilograms* (not *dynes*) of effort. Thus, when the force (F) and the weight acted upon (w) are both equal to 1 kilogram (as in the case of a body falling vertically, in vacuo), the rate of acceleration will be 9.81 metres per second, per second. If the weight of a train, w, is to be expressed in metric tons, we will have

$$w = 1{,}000\,W$$

where w = weight in kilograms,
and W = " " tons of 1,000 kilograms.

Substituting for w, in equation 18a, we have

$$A = \frac{9.81\,F}{1{,}000\,W} = .00981\,\frac{F}{W} \qquad m(18b)$$

This equation may be used instead of equation 21a, if velocity is to be expressed as a space-rate *per second* instead of *per hour*. To transform the equation into one expressing acceleration in kilometres per hour per second, we note from the preceding table of equivalents that

1 metre per second = 3.6 kilometres per hour.

Hence, equation (19) becomes

$$3.6A = a$$

whence

$$A = \frac{a}{3.6} \qquad m(19)$$

Substituting in equation 18*b*, we have the equivalent form of equation 21*a*, or

$$\frac{a}{3.6} = .00981\,\frac{F}{W}$$

whence,

$$a = .03532\,\frac{F}{W} \qquad m(21a)$$

The values of F and W will, of course, depend on whether acceleration is to be expressed in terms of "A" or of "a."

Solving for F, we will have, from equation m (18*b*)

$$F = \frac{W\,A}{.00981} = 101.94\,W\,A \qquad m(22a)$$

and, from equation m(21*a*),

$$F = \frac{W\,a}{.03532} = 28.31\,W\,a, \qquad m(22)$$

Solving for W we will have, from equation m(18*b*),

$$W = .00981\frac{F}{A}\,; \qquad m(23a)$$

and, from equation m(21*a*)

$$W = .03532\,\frac{F}{a} \qquad m(23)$$

Equation (24) remains unchanged, but the numerical value of P will evidently depend upon whether the value of F be taken from equation m(22*a*) or from equation m(22); in other words, it will depend upon the unit of acceleration assumed (whether "A" or "a").

Equations (25, 25*a* and 26) will retain the same form, the constant 91.1 being, of course, replaced by either of the corresponding metric constants given in equations m(22*a*) or m(22), according to the unit of acceleration adopted.

The last three equations will also retain the same form, and the values obtained for A' will likewise depend upon the unit of acceleration adopted.

The time-rate of velocity "k" will evidently have a different numerical value according to the unit of acceleration used.

Equation $m(19)$ shows that its numerical value will be 3.6 greater when acceleration is expressed in kilometres per hour per second ("a" units), than when it is expressed in metres per second per second ("A" units.")

Appendix C.—All the equations retain the same form. The numerical values obtained by means of the various formulæ will obviously depend upon the units of speed and acceleration adopted, since these govern the values of the speed increments ($d\,y$) and of the acceleration coefficients (k).

Appendix D.—When velocity (y) is expressed in *kilometres per hour*, the equations will all retain the same form. Distances will then be measured in kilometres, the values taken for k being those obtained by reference to equation $m(21a)$. When velocity is expressed in *metres per second*, the constant 3,600 disappears from equations (d) (e) (f) (k) (l) (m). Distances will then be measured in metres, the values taken for k being those obtained by reference to equation $m(18b)$.

The modified forms of these equations (which, it should be carefully noted, apply only when acceleration is measured in "A" units), will be:

$$s = \frac{y^2}{2k} \qquad m(d)$$

$$K = \sqrt{2ks} \qquad m(e)$$

$$x = \frac{\sqrt{2ks}}{k} \qquad m(f)$$

$$s = \frac{Y^2 - a^2}{2k} \qquad m(k)$$

$$y = \sqrt{2ks + a^2} \qquad m(l)$$

$$s = \frac{y^2 - a^2}{2k} \qquad m(m)$$

Specific Equations.—The equations (I.) to (XII.) inclusive, contained in the body of the paper are mostly derived or adapted from the general equations given in the appendix sections A, B, C, D, of the paper.

The following tables give, in parallel columns, the modified forms of each of these equations, when adapted for the metric system:

TABLE III.—(APPENDIX E.)

No.	First Term Same for All.	Last Term of Equation.		
		As Given in the Paper.	Modified for Metric System.	
			For "A" Units.	For "a" Units.
I	$\frac{dv}{dt}$	$= k \pm k' \pm k'' \pm$ etc.	same	same
II	F	$= .01098 \frac{F}{W}$	$= .00981 \frac{F}{W}$	$= .03532 \frac{F}{W}$
III	A'	$= \frac{.01098}{W} (\phi \pm \phi' \pm$ etc.)	$= \frac{.00981}{W} (\phi \pm$ etc.)	$= \frac{.03532}{W} (\phi \pm$ etc.)
IV	A'	$= .01098 (\phi \pm \phi' \pm$ etc.)	$= .00981 (\phi \pm$ etc)	$= .03532 (\phi \pm$ etc.)
V	A'	$= .01098 (\phi - f - c \pm G)$	$= .00981 (P - f - c \pm G)$	$= .03532 (P -$ etc.)
VI	ϕ	$= P - f - c \pm G$	same	same
VII	$-A'$	$= .01098 (-f - c \pm G)$	$= .00981 (-f - c \pm G)$	$= .03532 (-f - c \pm G)$
VIII	$-A'$	$= -.01098 f$	$= -.00981 f$	$= -.03532 f$
IX	$-A'$	$= -.0198 (-B - f - c \pm G)$	$= -.00981 (-B -$ etc.)	$= -.03532 (-B -$ etc.)
X	$-A'$	$= -1.647 \pm (.01098 G)$	$= -.73 \pm (.00981 G)$	$= -2.65 \pm (.03532 G)$
XI	N	$= \frac{20}{b}$	$= \frac{22.04}{b'*}$	$= \frac{22.04}{b'*}$
XII	G	$= \frac{N b}{20} = .05 N b$	$= \frac{N b}{22} = .045 N b$	same

*Where b' = increased train resistance in kilograms per degree of track curvature.

Metric Curve Plotting.—The methods of curve plotting described in the paper can also be employed in plotting "metric" speed-time curves. In using the Chart Method, however, special "metric" charts of Acceleration Coefficients and of Reciprocals will be required; and these charts will have to be prepared with special reference to the particular unit of acceleration employed.

Chart of Coefficients.—If acceleration is to be measured in "A" units (*i. e.*, in metres per second per second), the ordinates in the chart of coefficients will represent values of the acceleration coefficients such as determined by equation *m*(18*b*), and the abscissæ will represent speeds, expressed in metres per second. If acceleration is to be measured in "a" units (*i. e.*, in kilometres per hour per second), the ordinates will represent values of the acceleration coefficients such as determined by equation *m*(21*a*);

and the abscissæ will represent speeds expressed in kilometres per hour.

If the Chart of Coefficients is to have approximately the same range as the Chart shown in Fig. 9, the scales must be approximately as follows: For " A " units of acceleration, the scale of coefficients (ordinates) must read to about 1.2 metres per second per second, and the scale of abscissæ must read to about 32 metres per second; for " a " units of acceleration, the scale of ordinates must read to about 4.0 kilometres per hour per second; and the scale of abscissæ must read to about 115 kilometres per hour. The scale divisions should obviously be larger in the Chart for " A " units than in the Chart for " a " units.

The gradient percentage lines will be straight just as they are in Fig. 9, but their distances from the axis of x will be different in the two cases. A grade of 1 per cent. will represent a force (F) of 10 kilograms per ton, in both cases; but the numerical value of the acceleration produced by this effort will depend upon the unit of acceleration used. In " A " units, we would have by equation $m(18b)$,

$$A = .00981 \times 10 = .0981 \text{ metres per second per second.}$$

and, in " a " units, we would have, by equation $m(21a)$,

$$a = .03532 \times 10 = .3532 \text{ km. per hour per second.}$$

This means that the scale of gradient percentages at the right hand end of the Chart would be such that the line of equivalent acceleration for a 1% grade would be distant from the axis of x by an amount equal, respectively, to .0981 metre per second per second for " A " units, and to 0.3532 km. per hour per second for " a " units, when measured on the scale of acceleration coefficients at the left-hand end of the Chart. The corresponding line for a gradient of n per cent. would obviously be placed at n times the said distance.

Chart of Reciprocals.—The scale of ordinates in the Chart of Reciprocals will be the same as in the Chart of Coefficients, for reasons explained in the paper. The scale of abscissæ may be made as desired. The scale being arbitrary, it may be the same for the Charts of Reciprocals used for both " A " and " a " units.

Use of Charts.—The process of plotting " metric " speed time curves by means of the Metric Charts just described, is substantially the same as indicated in the paper for plotting curves by means of the Charts shown in Figs. 9 and 10.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Nineteenth Annual Convention.

Great Barrington, Mass., June 17–21.

In order that the professional work of the Convention might begin promptly on June 18th, the Committee on Papers and Committee on Transportation, arranged for a special train leaving New York at 2 o'clock June 17th, and reaching Great Barrington at 5.30 P. M. Seventy-three members and guests availed themselves of this arrangement, in order that they might attend a reception in their honor, which the Local Committee in conjunction with the Thursday Morning Club had planned for that evening.

At nine o'clock the members and guests assembled in the Music Room of the Berkshire Inn, were cordially greeted by the ladies and gentlemen of the local Reception Committee. An address of welcome by Mr. William Stanley, Chairman of the Local Committee, was given as follows:

"Members of the Institute, Ladies and Gentlemen:—A very pleasant though unfamiliar duty has fallen to my lot this evening, for I am instructed by the good people of Great Barrington, by their neighbors in the adjacent villages, by the Mayor and the citizens of Pittsfield, in fact, by all the inhabitants of the hills and valleys of Berkshire, to extend to you a most hearty welcome. A year ago, when we sent you an invitation to hold your meeting among us, we were well aware that we could not hope to offer to you the attractions that are most intimately associated with your profession, attractions which you have been accustomed to find when assembled in the larger cities of the country, for we have few engineering enterprises, and the arts and sciences are not widely practiced among us. I may as well confess it—we are a simple pastoral people dwelling among these hills. To us no pastures or meadows are so green, no mountain brooks so joyous, no pines so fragrant, no elms so stately as those of Berkshire. Upon this very spot, some seventy years ago, there dwelt one of the sweetest singers of the era, who, in "Thanatopsis," "The Water Fowl," "Green River," and other poems, expressed the inspiration he gathered among these hills. A little

way up the valley Hawthorne lived beside a lake and wrote those wonderful stories that have made his name immortal. From Stockbridge, near at hand, came Field, the man who dared to lay the first cable beneath an ocean. Just down the street, in an ancient house, Franklin Leonard Pope, second President of this INSTITUTE, passed his boyhood days and met his most untimely death; and so I might almost indefinitely extend the list of those who, carrying from these hills and valleys most noble thoughts have done much for their country. While we rely to some extent upon the natural beauties of our country to make your visit pleasant and agreeable, we would hardly have dared to undertake the responsibility of entertaining you on this occasion had nature been our only attraction. We shall hope to persuade you that not even June arrayed in her loveliest robes is as fair as are the ladies who are to assist us during your visit. Our little village can point with pride to the Thursday Morning Club. We have entrusted to them the conduct of such functions as we shall be able to offer to you, a decision which I am sure you will heartily endorse. I know that I am expressing the sentiment of your hosts this evening if I have made plain to you in this brief message that our most cordial greeting is not only extended to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, but that it also has a personal significance to each and every one of its members."

By special request of President Steinmetz, the response in behalf of the INSTITUTE was made by Past-President Martin, who eloquently thanked the Committee for the hearty welcome extended to its members, and in line with Mr. Stanley's remarks paid a feeling tribute to the memory of the late Past President, Franklin Leonard Pope.

NINETEENTH ANNUAL CONVENTION.

OPENING SESSION.

Discussion at Great Barrington, June 18th. Papers by F. G. Baum, M. Leblanc, H. W. Buck and Charles P. Steinmetz.

PRESIDENT STEINMETZ:—Gentlemen, Members of the INSTITUTE and Guests: I now call to order the Nineteenth Annual Convention of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Following our previous practice, we hold the Annual Convention outside of the place of our regular monthly meeting, this time in a very pleasant country village, and I hope you will enjoy the convention very much, especially as we have been so very well and cordially received, in somewhat striking contrast to some experiences in former times.

[After presentation of papers by the authors named above, the discussion proceeded as follows:]

DR. F. A. C. PERRINE:—I have some notes here for closing the discussion on Mr. Baum's paper which I think we might as well read. Mr. Baum wrote me a letter that I thought might possibly be required in answering some questions, but as I did not hear the questions, I will read the letter anyway.

"STOCKTON, CAL., Jan. 1, 1901.

DR. F. A. C. PERRINE.

DEAR SIR:—As I telegraphed you on December 28, 1900, I made a practical test of the compensator at Stockton. I was able to make arrangements with Mr. Adams to start 15, 20, 25 and 75 h.p. motors on the G. E. 100 k.w. synchronous motor, which is now being run as a generator. This generator is a bad regulator (having been built for motor work), the reactive pressure being about 20 per cent. on full load current, and the starting of the 75 h.p. Westinghouse type C, (Farmer's Union) motor is as severe a test as you will ever get in practice.

I thought the conditions here for giving the compensator a severe test were better than at Maryville, and therefore did not go up there. I am convinced that I could start this 75 h.p. motor on a 50 k.w. generator, and not cause more than a momentary dip of the lights.

The compensator was driven in synchronism by a gearing on the shaft. This gearing is satisfactory, but usually when several alternators are to be compensated, the compensator would be driven by a small synchronous motor. A synchronous motor for the purpose can be made by winding a $\frac{1}{4}$ h.p. motor frame. Since a $1\frac{1}{4}$ h.p. motor will make a compensator large enough to take care of a 2,000 k.w. generator or station, you need not go to any expense in getting out new patterns, etc., for the compensator. For smaller generators 50 to 200 or 300 k.w., a smaller machine than the $\frac{1}{4}$ h.p. motor could be used for the compensator.

Starting test of 20 h.p. G. E. (Hyatt) motor, on 100 k.w. G. E.

generator. (Speed change in engine varies the voltage from 114 to 118; railroad on same engine.)

	CONDITIONS BEFORE START	START	MOTOR RUNNING.
Alternating Amperes,	6.25	15	9
" Voltage,	116.	114	116
Exciter Amperes,	9.25	10	9.5

No change in rheostat necessary. Voltage dips to 114 but returns to 116 in less than two seconds. This dip is on account of the lag in magnetism spoken of.

Without compensator, when this motor is started, the voltage drops 10 to 20 volts, and must be brought back by turning rheostat handle. Station must be notified when motor is thrown on or off. No notice is necessary when compensator is in.

Start 75 h.p. Westinghouse type C (Farmer's Union) motor on 100 k.w. G. E, generator.

	BEFORE START.	START.	MOTOR RUNNING.
Alternating Amperes	10	Over 50 amperes.	15
" Voltage,	116	95	116
Exciter Amperes,	9.75	12.75	11.5
		Ammeter needle off scale.	

No change in rheostat. Voltage dips to 95, but comes back to 116 in about two seconds. Note that the exciting current immediately jumps from 9.75 to 12.75, an increase of 32 per cent., and then gradually drops as the speed of the motor increases, to 11.5 amperes, where it remains. Rheostat was not touched. When motor is cut off, alternator voltage remains at 116.

Without compensator, the voltage drops when this motor is started to about 85, and remains down about 100 until brought up by station attendant. Station must be notified when the motor is thrown on or off. No notice is necessary when compensator is used.

Yours truly,

(Signed) F. G. BAUM.

PROF. C. A. ADAMS:—I should like to ask Dr. Perrine about the compensator.

DR. PERRINE:—The sparking is one of the things that Mr. Baum attempts to get rid of by the arrangement shown in Fig. 6, where he obtains a very small current from the compensator largely to do away with sparking, and uses that to excite an auxiliary exciter, which in turn excites the extra winding of the excited field. When he attempts to use a compensator directly, he is apt to get considerable sparking, but he gets rid of the sparking by making the current very small—a current of the maximum of an ampere is sufficient to do all the work when he uses this auxiliary exciter.

PROF. ADAMS:—My inquiry was if in this latter case he gets rid of the sparking.

DR. PERRINE:—He does not get rid of it, but he uses such a small current it does no harm.

PROF. ADAMS:—How would you get rid of sparking in using 1,500 k.w. instead of 200 k.w.?

DR. PERRINE:—The compensator in any case is a small outfit; he uses that to act on a secondary exciter, and he always keeps his current in the compensator small, even when compensating from a large generator.

MR. ADAMS:—It would be possible, then, to use a small compensator for the exciter, regardless of the size of the generator?

DR. PERRINE:—Yes, provided the winding of the secondary exciter is correct; that is, he need not change the current in the compensator at all.

Concerning Mr. Buck's paper there are a few things of which I would like information from Mr. Buck. At the time the original plant was built, we heard a great deal of the manner of carrying the heavy shaft and I would like to know whether there has been any change in the design of the thrust bearings along the shaft which carry that shaft. Also whether anything has been done to obviate the extreme wabbling of the 30-inch shaft. I was in the wheel-pit of the old power-house a short time ago with some Western engineers, and we all noticed that the 30-inch shaft seemed to be running out an inch or two, and the question was raised, even though it may be considered trivial, whether it really was not straining the material, and bringing about the effect that we commonly know as crystallization, which is not crystallization, but simply the exceeding of the elastic limit to a very small extent continuously, which ultimately overcomes the elasticity of the entire material, and it appeared to be a good thing to get rid of.

On the seventh page of the paper is given the guaranteed and test efficiencies of the old machines, and nothing is said of the efficiencies of the new machines. I do not presume from those efficiencies they can be very much greater, and may be less, but it would be interesting if we knew approximately what those efficiencies are.

I agree with Mr. Buck entirely in the question of the arrangement of his switchboard, namely, that the bench system in combination with the instruments on panels is bad. The bench system to my mind, is only practical where the station is so small that the instruments can be arranged so close together that lines drawn from the bench will come directly on the switchboard panels. What I mean by that is this: if we have a switchboard with instruments on, and divided into panels, and an operating table of smaller dimensions, then the benchboard is permissible if the switchboard is short enough to be within the eye of the attendant, and his small switches located with lines drawn showing what they represent on the instrument board; then when a man puts his hand on any particular switch, by following his lines he goes directly to the instruments he is operating. But I

agree with Mr. Buck entirely, it is poor practice to have an operating table at one point and the instruments that are operated from that table 20 or 30 feet on either side. Obviously, a man cannot tell what he is doing; and furthermore, the advantage of having all of the switches at any station under a man's immediate hand is more or less fictitious. It is rare that a man at any one time will want to handle more than two machines, and they are generally adjacent machines; the cases are 99 out of 100 where an operator has not before him all the switches he needs to have. In this Niagara station I first saw the method of putting all the recording apparatus in the superintendent's office, and it seemed to me that is really where they belong. There is only one thing to my mind worse than putting wattmeters on the switchboard, and that is lightning arresters. The operator at the station should have before him such instruments and such apparatus as he must necessarily use in handling the station, and only such apparatus. If the station operator has before him instruments that he does not need to use in operating the station, and whose indications he does not need to consider, he gradually loses his respect for all indication of instruments; and I believe that there should be before the station operator only the things he has to pay attention to and use. This idea of putting on the switchboard all kinds of phase indicators, and frequency indicators and indicators of everything under the sun, is to my mind an absolutely vicious practice. The station attendant ought to have before him such apparatus that every movement of a needle tells him something, and he should not have wattmeters, for example, any more on his switchboard than he should have lightning arresters; and with the three-phase generator he does not need three voltmeters and three ammeters; and to put apparatus there that the station attendant positively cannot control, I think is confusing to his mind. This Niagara plant is the first one where this principle was put in practice, and I am very glad to see it carried out in this latest development. The change from an external revolving field to the internal revolving field seems, in our ideas of the Niagara plant, very radical; but the speeds of those generators are not greater than the speeds that are being used in other revolving field plants and the construction I imagine is very much similar; and it seems to me the change is a distinct practical improvement in the construction.

MR. BUCK:—Replying to Dr. Perrine, the average weight of the rotating parts of the machinery in power-house No. 2 will be carried as in the old plant, upon a hydraulic step at the bottom of the shaft, and the variations in downward thrust due to variations in head of water, will be taken care of by an oil thrust bearing near the top of the shaft, which is operated by oil under pressure of several hundred pounds per square inch. The friction of this oil thrust bearing is so slight that when the machine is standing still a man can turn it around by hand.

In regard to the apparent eccentricity of the shaft, I think that

it is due to the shaft being hollow, and made of lapped boiler iron. Every time a lap goes around it looks as if the shaft were out of true, but the shaft as a whole is centered so that there is no wabble on the bearings. The test efficiency of the internal field generators was not given for the reason that these machines have not yet been tested. The guaranteed efficiency is 2/10 of 1 per cent. lower at full load, than that of the external field generators.

In the old power-house the indicating and recording wattmeters are both placed in the office of the superintendent. In the new plant the indicating meters will be transferred to the switchboard and the recording wattmeters only retained in the office of the superintendent.

MR. A. V. GARRATT:—The drawing is on so small a scale that it is difficult to tell what style of gate the turbine has. It will be interesting if Mr. Buck will advise us as to what type of turbine is being used, and also where turbines of this particular type have been installed, if at all, in this country, and what success has been obtained with them in regard to speed regulation.

MR. BUCK:—I do not think that any turbines of this exact design have yet been installed in this country, but there are a number installed in Switzerland and other European countries, and I understand that the results obtained have been very satisfactory. In this design, the water coming down the penstock enters the wheel case, which is spherical in form, and from there discharges inward through a double set of buckets which are controlled by ring gates from above. From the inside of the rotating part, the water is drawn out through double draft tubes as shown.

MR. P. H. THOMAS:—There is a little more, it seems to me, that should be said on the uses of benchboards in these large systems. Of course it is very important to have the attendant see the instruments on the panel on which he is going to throw switches, but it is also important that he should know as well the actual connections on the rest of the system. In many cases I should think the latter would be more important than seeing the indications of the instruments. A complete knowledge of the connections of the system is very easily obtained by the benchboard system. Undoubtedly, however, some plants can be more satisfactorily handled with the feeder system than with a benchboard.

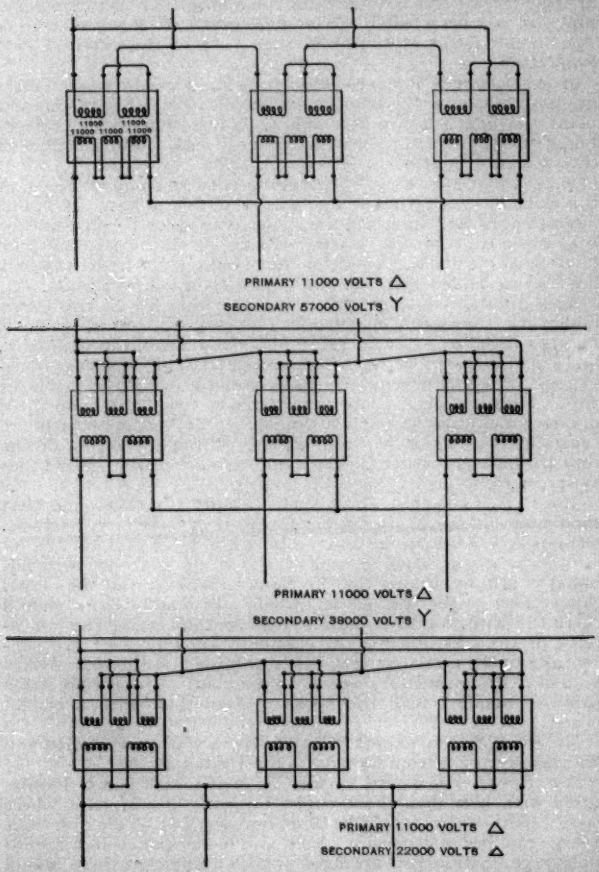
Mr. Buck, do you expect to pay duty on your power when you are transferring it from Canada to the United States?

MR. BUCK:—In regard to Mr. Thomas's first point, I quite agree with him that there might be some special case where benchboard control would be of advantage, but where you have a large number of generator panels and feeder panels it is impossible to get instruments arranged in such a way that there would be no confusion.

In regard to the duty on power, that matter was settled, I be-

lieve, by Congress and also by the Canadian Parliament, and a reciprocal arrangement arrived at.

PRESIDENT STEINMETZ:—In Mr. Buck's paper the statement



is made that the output of the Canada plant is intended for long-distance transmission to Toronto, I believe. We would all be interested to hear somewhat more of what is intended to be done

there and what work is in progress regarding the transmission. The distance is rather long, pretty well up to 100 miles, and the climate is not so lovely as in southern California, and it would be quite interesting to hear what Niagara expects to do.

MR. BUCK:—Up to the present time nothing very definite has been done upon the Toronto transmission line, but negotiations are now pending and it is likely that construction will start before long. The line is to be arranged for operation at either 40,000 or 60,000 volts. The arrangement of step-up transformers selected for this transmission may be of interest to the INSTITUTE, and I will illustrate the construction on the blackboard. [See Fig. 1]. The transformers are designed with five similar coils, two of which constitute one winding and three the other winding, either of which can be used interchangeably as primary and secondary. By the various combination of coils as shown in the sketch, any of the voltages shown can be used with the full copper efficiency of the transformers.

PRESIDENT STEINMETZ:—If there is no further discussion today, then a motion to adjourn will be in order. Before we adjourn I desire to say this: We have postponed two papers which we had scheduled for this forenoon's meeting. We have a very large programme for to-morrow and the following day, therefore it will be absolutely necessary to start the meeting punctually at 9 o'clock.

Announcement regarding social features in connection with the Convention were then made by Mr. Stanley, after which the session adjourned.

In the afternoon the members with their ladies were entertained at a Lawn Tea, under the auspices of the Thursday Morning Club, at Brookside, the residence of Mr. and Mrs. William Stanley.

In the evening a Lantern Exhibition arranged by the Committee on Papers was given by the INSTITUTE at the Town Hall. Groups of slides upon various subjects were shown and described by the members named, who were introduced by the Secretary: Messrs. T. Commerford Martin, W. B. Spellmire, F. A. C. Perrine and W. J. Jenks.

Discussion.

Mr. Mailloux's Paper on Single-Phase Alternators.

[See p. 611, May issue.]

President Steinmetz: Gentlemen: You have listened to a very interesting paper by Mr. Mailloux concerning some interesting experiments made by him in connection with the application and use of single-phase alternators, as I might say, to help out the polyphase system. Not only to help out the polyphase system, but also to help out the polyphase system when it is not there, that is, to produce it.

Mr. Potter:—I believe the author said the single-phase alternators were first synchronized with the three-phase current.

Mr. Mailloux:—Yes.

Mr. Potter:—Would it not be possible to start the system by the steam station only, by synchronizing the two single-phase alternators in quarter-phase relation, instead of synchronizing by the three-phase from the water power station, which I understand was done in the experiment referred to.

Mr. Mailloux:—There is no difficulty in bringing the alternators into quarter-phase relation. The difficulty in following Mr. Potter's plan, is to *keep* the alternators in quarter-phase relation long enough to get the rotary converter started. The experiment might succeed and is worth trying if the hypothesis which I state is correct, namely, that we have a case where each single-phase alternator is really coupled with one corresponding phase of the rotary converter acting as a synchronous motor, then it would readily be seen that it makes no difference whether both phases are started. If we could start the rotary converter and run it at any speed at which it would excite itself, then the moment that it excited itself, we could couple one of the alternators in synchronism with it, by reducing the speed of the alternator to the correct frequency. When that has been done we could speed up the first engine, and of course the rotary converter, acting as a single-phase synchronous motor, would follow it until the proper speed desired is attained. At that time the second alternator could be coupled with it, or it could, in fact, be connected with it at a lower frequency, and then by opening the throttles of the two engines we could raise the speed to any point desired; if the hypothesis advanced is a correct one, it would seem possible to be able to start the outfit without the assistance of the line current. In the experiments tried, the line current was always used first to start the rotary converter, because that was the easiest way of doing it. We had no other means of starting the rotary converter there. You can readily understand that the arc light machines belted from it could not be used to run the rotary converter and get it up to speed. We could only do it by starting the water power station and getting a certain amount of potential on the line, which we usually raised to the full potential, and after the rotary converter was started, there of course would be no difficulty whatever.

In the paper, I make the statement that the rotary converter

acts as an electromagnetic elastic coupling. The word elastic is intended to allude to the fact, which is well understood, that no correction can take place unless there is a slight change in frequency, because, if the phase relations were maintained absolutely perfect, there would be no possibility of any cross-current or synchronizing current between any phase of the alternating current and the corresponding single-phase alternator; we therefore conclude that there is a slight change or variation of frequency; and I believe if we had proper means of sufficiently accurate measurement of angular velocities, it would be clearly shown that there is a slight change of frequency and variation back and forth in the frequency. That is what is intended by the term elastic. It is the same thing as if we had a coupling which is somewhat yielding and which allows of a certain amount of motion between the two; and my reference to the effect of the difference in frequency was intended to advert to the possibility that the amount of angular variation, that is to say the *range* of elasticity in the electromagnetic coupling, would probably be, to some extent, a function of the frequency.

MR. H. E. HEATH:—In regard to this experiment, which of course is very interesting, I notice that the rotary has a direct current, and it would be quite possible to excite its field from an outside source. If that were done, and the alternator before starting was properly connected, would it not be possible to start the engines together and make the rotary pick up as the engine started?

MR. MAILLOUX:—I believe that it would, and you will find it stated in the paper that the plant will eventually include a storage battery. When that is installed, which unfortunately was not the case at the time of the experiment, it would be possible not only to excite the rotary transformer from the storage battery—that would be in fact the normal way in which it would be done—but it will also be possible to put it in motion. Under those conditions the storage battery current would be used not only as a means of keeping the rotary converter in motion, but it would also act as a " buffer " or as " ballast " capable of taking care of any fluctuations occurring between the two phases. If we had had the storage battery we would not have hesitated in using the system practically, because we would not only have a motor effect transferred from one phase to the other, namely, from the phase which is increasing in frequency to that which is lagging, but we might also have a motor effect due to current taken out of the storage battery and tending to speed up the rotary transformer, thereby supplementing the correcting effect taking place between the two alternators considered by themselves. The addition of a storage battery will greatly add to the elasticity and the value of this method. I feel so well satisfied with the practical results that I would not hesitate at all under like condition to use a method of operation of that kind.

President Steinmetz then illustrated on the blackboard an experiment made by himself some years ago.

MR. JOHN MURPHY:—Mr. Mailloux's diagram (Fig. 1) would represent exactly the conditions existing at Ottawa if a two-phase rotary converter and two-phase generators were substituted for the three-phase machines, and, if a 2,200-volt four-wire line were drawn instead of the 25,000-volt line. On many occasions we have run the two-phase rotary from one of our single-phase generators, starting it up by direct current from our storage battery, synchronizing it and throwing it onto one of our single-phase machines. Every evening we operate a single-phase generator in parallel with one phase of our two-phase machines. We have a large incandescent lighting load and we transfer some circuits from one phase to the other in order to load up the single-phase generator during peak hours. I intended to try the experiment which Mr. Mailloux has shown can be successfully carried out, because the single-phase generator works so nicely in parallel with the two-phase generators, and the rotary converter ran so well as a single-phaser that I felt certain the second single-phase generator could be connected with the other phase of the rotary converter all right. I am delighted to hear that it has been successfully done.

MR. MAILLOUX:—I consider the experiments related by Mr. Murphy to be a very satisfactory confirmation of the hypothesis which I advanced here to explain the operation under those conditions. As stated in the paper, when there is a change in phases between the machines, such as occurred in this case, the only complication that is introduced is that the energy for correcting the phase relation, instead of being sent on one phase only, is sent partly over two phases; in other words, if one of the single-phase alternators tends to get out of step with the other single-phase alternator, the corrected impulse which it sends to or receives from the electromagnetic coupling or the rotary converter, will be sent as a single-phase impulse as far as the Scott transformer, but at that point it would divide in certain proportions so as to be sent beyond that point, partly through two of the phases of the three-phase system; so, really, the apparent complication introduced in this case by the change in phases from two-phase to three-phase does not affect the theory nor the operation. The problem remains still quite as simple as it would be if we were dealing with a two-phase rotary converter and two single-phase alternators, or with a three-phase rotary transformer and three single-phase alternators.

PRESIDENT STEINMETZ:—If there is no further discussion on Mr. Mailloux's paper, I call upon Mr. Arnold, to abstract his paper on the "Method of Ascertaining from Dynamometer Car Records the Power Required to Operate the Mott Haven Division of the N. Y. C. & H. R. R. R. and the Relative Costs of Operation by Steam and Electricity."

[Mr. Arnold then read his paper. See p. 623, May issue.]

DISCUSSION.

Papers by A. H. Armstrong, W. B. Potter and B. J. Arnold, and by C. O. Mailloux, and B. J. Arnold, at Great Barrington, Mass., June 19, 1902.

DR. PERRINE:—I have received a telegram from the Pacific Coast Transmission Association to the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. They are in meeting at this time. It refers particularly to the underwriters' rule that was proposed, that constant tension lines of over 3,500 volts should not be installed within 75 feet of a building; and the enforcement of that rule would probably kill transmission lines. We are all interested in the rule, and we have a committee to consider it. It is very vital, and consequently they have telegraphed me as follows:

"Transmission convention to-day unanimously adopted resolutions condemning enactment of proposed restriction of overhead line voltages as unwarranted, unjustifiable and eminently prejudical to vested interests and appointing you commissioner to present same to INSTITUTE."

PRESIDENT STEINMETZ:—Referring to the telegram which has just come to us through Dr. Perrine, I believe it is proper to refer this matter to the Committee on the National Electric Code, which is a special committee of the INSTITUTE. That it be instructed to consider it and give expression of the feeling of the Board of Directors against such proposed rules. Now, I believe we can leave the matter in Dr. Perrine's hands, because Dr. Perrine is a member of this committee.

Secretary Pope then presented to the Convention and read the following letter:

BERLIN, June 9, 1902.

MR. R. W. POPE, Secretary.

DEAR SIR:—Present to the INSTITUTE my most sincere regrets that I am unable to be present. I trust that the Great Barrington meeting may be most successful and may give the INSTITUTE an impetus for the coming year.

Let every one determine to do his part in continuing the excellent work of the past year under President Steinmetz, and making the INSTITUTE a more effective factor in the progress of American electrical engineering.

Most sincerely,
CHAS. F. SCOTT.

PRESIDENT STEINMETZ:—There being no further announcements, discussion is now in order. We should all be very delighted to hear Mr. Sprague open the discussion, than whom nobody is more able, more willing and more apt to lead on this topic, to which he has not only given attention, but with which he has been living since the early days of electrical railroading.

Discussion.

Mr. F. J. Sprague:—Mr. President and Members: I had not intended to take part in the discussion to-day, and for certain reasons would prefer to remain in the background. The paper which has been read by Mr. Arnold is, however, of such importance that I think that I may personally, and for the Institute, express our appreciation of what is one of the most important communications which will be presented at this meeting. This is so not only because of the character of the paper itself, but because it deals with a problem the solution of which is very urgent, and is, moreover, of special interest to those who live in, or who come to New York. If not arriving by way of the ferries and the railways connecting therewith, the passenger must come over the New York Central, Harlem or New Haven roads, and is thereby confronted with the necessity of entering New York through a tunnel which, at the present moment at least, does not offer much in the way of attraction. Mr. Arnold's paper is, I believe, an abbreviation from reports made by him to the New York Central Railroad Company from time to time, and deals with the general possibility of electric operation and the relative economies of steam and electric motive power for the terminal service between Mott Haven and the Grand Central Depot. Perhaps it is inexpedient for Mr. Arnold, under existing circumstances to say much more, or to discuss other phases of the problem.

The subject is one to which I have given considerable attention, and I am glad to note that the power requirements agree very closely, considering the changed conditions, with the result of a similar investigation made under my direction some three years ago. Mr. Arnold has very wisely confined himself to the problem of train movements within the limits of New York City, instead of complicating his report and confusing his clients by speculations as to the possibilities of through electric service, the methods for accomplishing which are still, and for some time are likely to be, matters of discussion and probable disagreement among the ablest engineers. For the specified service, the use of continuous current motors, to be operated at a moderate pressure, is a safe, and the only safe recommendation. The paper makes a special comparison of steam and electric operation in the matter of economy, with the result that no special advantage is shown in favor of one or the other. Economy, however, is in this particular case the least important consideration, and I do not doubt that Mr. Arnold believes with me that while this comparison is necessary, there is no question, not only as to the practical possibility of electric operation, but of its wisdom and even imperative need on the score of comfort and safety, despite recent somewhat pessimistic assertions to the contrary; and, furthermore, that the financial results would also entirely justify the change. On account of the special nature of the problem, if

the railway company defers the adoption of electricity until some great saving in car-mile operation is manifest, steam will continue for a long time to be the motive power in the tunnel. Safety, cleanliness, and comfort, however, being assured, increased earnings will most assuredly result from increased traffic.

The problem is a two-fold one—the replacing of the steam locomotive on through trains at some point above Mott Haven, and the operation of the suburban service, at first possibly by replacing the steam locomotives within a given zone, and later by the complete adoption of electricity within twenty or thirty miles of New York. The requirements have to be met in different ways. At present both train services are operated by steam locomotives. The through service must remain such, but the suburban can be readily changed. No less than ten or a dozen types and sizes of locomotives are now in use, pulling at limited speeds trains varying in weight from 150 to 600 or 700 tons. It would seem, therefore, that so far as locomotive service is concerned, it can be best performed by units of ,say, 30 to 35 tons weight, and of 700 to 800 h.p., these units to be so equipped and controlled that one may be used for the lighter service, and any two, operated as a single unit, for the heavier. These conditions make imperative what has already been well settled—preferably electrical instead of hand operation of control equipments, and the grouping and simultaneous control of units; in short, the multiple-unit system of operation. For suburban service, individual equipment of cars and like control of any required number is now beyond question.

Another thing must be borne in mind, that is, that electrical equipment not only will ensure greater safety of operation because the tunnel will then be clear of smoke and condensed steam, but the adoption of electrical control will leave the engineer free to devote himself to the safe piloting of his train, untrammelled by the distraction of other duties, the importance of which must be manifest to any one who is familiar with the strain on a locomotive engineer, watching and listening for signals. That the train movements in the tunnel can be effectively made by electrical power must be evident to any unprejudiced investigator, and so far as the possibilities of the case are concerned, I would not hesitate—and I feel sure that I voice the conviction and sentiments of others in the room—to undertake the feat of hauling the heaviest train from Mott Haven to Grand Central Station with electric power on schedule time within six months. Of course, such a demonstration would be a special one and for a single train, for considering the many civil engineering and railway problems involved, from two to three years are necessary to make a general change.

MR. F. S. PEARSON:—Mr. President and Gentlemen:—It gives me pleasure to be here. It is the first meeting of the INSTITUTE that I have been able to attend for seven or eight years. I have little to say for I have been called upon very unexpectedly, and

I am not much of a public speaker, but I have been greatly interested to-day in the papers, as they show the careful and detailed work which is being done on this question of electrical transportation. In Mr. Arnold's paper particularly, I have been impressed with the enormous amount of work that he has been able to do since August, 1901. I am trying to imagine that there were one or two years more between this time and the date on which he said that he commenced his investigation.

MR. B. J. ARNOLD:—The work was done in about four months.

MR. PEARSON:—You must have worked hard—25 hours a day at it. In regard to the remarks of Mr. Sprague, I think that electricity is certain to supplant steam to a very great extent in the next few years, but I look for the greatest development, not in the handling of the long-distance freight traffic, as a great many sanguine engineers are prophesying, but more in the suburban work and in long distance, exceedingly high-speed transportation. The tendency of our race is to hurry. We have just had two 20-hour trains put on between New York and Chicago, and I hope to see 10-hour trains running there within the next ten years; it is perfectly feasible with electricity to do this. With steam, the limits in speed are being well-nigh reached, on account of the limitations of the boiler; but there is no reason, so far as I can see, from the point of safety or as regards power, why we could not make 120 to 150 miles an hour; I think this is the direction in which we electrical engineers will have to work in the next few years. In suburban work, of course, another phase of the question opens up, where an exceedingly high speed is required, but for very short distances; and that is where the great advantage of electricity for suburban work will lie. If we can take a road, 15, 20 or 30 miles in length, with perhaps 10 or 15 stops, and by obtaining a maximum speed of 60 to 100 miles an hour between stops, cut down the average running time to 50 per cent. of what it is to-day on the best steam surface lines, the advantage of our large cities is given to all the suburban public, and this rapid transit is sure to be demanded. The work which Mr. Arnold and Mr. Mailloux have done in the last few months will be of the greatest advantage to all engineers employed in practical development and construction work, who have not the time in most instances to do this detail work, which must necessarily precede construction, and upon which all final results of development must depend. For such careful work as this, which is so practically presented here to-day, the thanks of all engineers are due to those who devote their time so freely to it and so generously present the results to us. I will not take up any more of the time of the INSTITUTE, as I imagine there are others much better able to speak on this subject than I am. I have learned a great deal in the past two days, as in the past years of my membership I have learned from the papers at the meetings where I have not been able to be present.

MR. OBERLIN SMITH:—I think Mr. Pearson is right in saying

that the suburban traffic is an entirely separate problem from the high-speed long-distance railroad of the future. I think we must all admit that we cannot safely get these excessively high speeds of 120 to 180 miles an hour with the present form of track. I believe that electrical engineers are ready now to equip cars with transmission and driving apparatus, provided we have a proper roadway. We cannot, however, run upon ordinary tracks laid on the ground and subject to danger by reason of crossings, switches and other obstructions. Furthermore, the cars must be so confined to the track that they can by no means be derailed.

The development of such a railroad is not so difficult an electrical as a mechanical problem, but it is even more of a problem financially. Engineers, electrical, mechanical and civil, are all ready to tackle it and it would not take so very long to build a road and get cars running from Philadelphia to New York in from 30 to 45 minutes at perhaps 5 or 10 minute intervals; but we cannot do this on existing road beds.

The difficulties of financing an undertaking of the kind, especially the first one, will be enormous; and this is what will delay the new movement more than anything else. Possibly by the time that a Hudson River bridge is built, the financiers may be ready to build a roadbed of proper construction. If it is not sunk in the ground it should be elevated (absolutely isolated from all obstructions), and the cars so built that they cannot get off the track—for derailment is the great danger we have to fear. When the cars are mechanically confined and kept where they belong, the roadway and cars forming together a complete and harmonious machine, there is no difficulty whatever, from a mechanical standpoint, in operating them at three miles a minute.

The best place in the whole world to start this grand development of the 20th Century is doubtless between New York and Philadelphia—the only place on earth where two such large cities lie so near together. An experimental beginning might well be made on such part of the complete road as between New York and Newark. The traffic is already enormous, so that there would be no difficulty in getting plenty of passengers. Then, too, the "traveling habit" would enormously increase—with the embodied safety, speed, frequency, cleanliness and perhaps quietness, of the new system. Of course, one great difficulty, besides the mere financing of such a scheme, would be to overcome the opposition of the old roads, and to get proper terminals in places where there are already steam roads in competition.

PRESIDENT STEINMETZ: I see that Mr. Dodd is here. We should like to hear from him.

MR. S. T. DODD:—I have been very much interested in what Mr. Mailloux had to say, but I would not attempt to discuss a paper of that character without having looked into it a good deal more carefully. It has long been an idea of mine that there

ought to be some quick easy analytical method by which we could get at a solution of these problems. I have suggested such ideas to Mr. Mailloux once or twice, and his reply to my suggestion has always been that in the particular lines along which I was working it was impossible, and I have always found on further investigation that he was perfectly correct.

PRESIDENT STEINMETZ:—Gentlemen: There is no industry which has been developed as rapidly and to such enormous proportions as electrical railroading, but while this development has been very rapid, more rapid still has been the development of the theory of electrical railroading as shown by the papers presented at to-day's meeting. Now, while a few years ago the theory of electrical railroading consisted in putting any kind of electric motor on any kind of a car, and running it to see what it did, now, you see the speed, the time, etc., calculated with such refinement that engineers are no longer satisfied to assume the constant coefficient of friction, but carefully investigate and bring into the calculation, the variation of the friction with the speed, the momentum of the motor, etc., and succeed in getting simple and accurate results, not only theoretical, but they also gradually gather an enormous amount of experimental data not of the same character as years ago, but based on experiments carefully planned and still more carefully carried out, as shown in Messrs. Arnold and Potter's paper. It is interesting also to see to what refinement the theory gradually develops. The problem was once merely to take a man from one place and put him down in another place, to transport him from a distance. Now, you cannot do that instantly, it takes time; it would be rather uncomfortable to do it instantly; consequently, we have the speed question. Experience shows it would be uncomfortable to go at a uniform speed; to start at one place with full speed, and stop at the other place while at full speed; consequently, we have to consider acceleration; starting and gradually increasing to full speed and then decreasing until the stop. That brings in acceleration. There is one other feature brought out in Messrs. Arnold and Potter's paper: still further refining the matter, we must not start acceleration constantly. In acceleration we have a second differential coefficient of the distance; we must not do that instantly, but gradually increase acceleration to full acceleration, then gradually decrease it again. Then we have to begin to consider the third differential equation of distance, to get a maximum speed with minimum discomfort to the passenger. I look forward to the time when we shall have to consider the fourth and fifth differential. Without joking, it shows how important these things are, because, if by gradually increasing the acceleration we can run at an acceleration of three miles per hour per second, in rapid transit at very high speed—with very frequent stops, it may be the deciding feature of success between the possibility of carrying out the proposition, or the impossibility of carrying it out.

We have not heard yet from the exponents of alternating current railroads. Inasmuch as Mr. Arnold was the strongest advocate of the alternating current railway last year at Buffalo, we would like to hear from him.

MR. ARNOLD:—I have a word to say, but I prefer to say it after the discussion on my present paper is closed, because I have an extemporaneous speech in my pocket, and I want to read it to you.

MR. H. WARD LEONARD:—As some of the members of the INSTITUTE may remember, I suggested about ten years ago, in an INSTITUTE paper, a method of operating a long-distance railway, and it may perhaps be of interest, in connection with the present paper, to note the fact that there is at present under construction by the Oerlikon Works in Switzerland, a locomotive which is exactly such as I suggested at that time. The locomotive is one which will employ a single-phase alternating current, transmitted at about 15,000 volts, with about 75 miles between the power-houses. This single-phase alternating current will be fed to the locomotive and transformed by a motor generator upon the locomotive into a continuous current which will be supplied to the propelling motors upon the axles. The locomotive which is now under construction by the Oerlikon Works will be capable of developing 700 h.p. at the draw-bar, with a tractive effort of about 10,000 pounds at the draw-bar This I find compares about with Fig. 12 of Mr. Arnold's paper. The weight of the locomotive will be about 44 tons. Of course, all its weight will be upon the drivers. This also corresponds quite well with Fig. 12 of Mr. Arnold's paper, in which 45 tons is upon the drivers. It is expected by the Oerlikon Company that the efficiency of this locomotive will be about 75 per cent. The cost of the conductors, on account of the high voltage, will be comparatively low, being estimated at about $1,200 per mile. The advantageous features of this system are that there are no idle resistances used and there is no opening of heavy currents. The generator has a separately excited field and also the motors, and the variation of speed is accomplished by the variation of the voltage produced by the generator and supplied to the motor armatures, which are operating in constant separately-excited fields. This makes it possible to accelerate the load without any jerks, and it will accomplish that which is so much desired, and which Mr. Steinmetz has referred to; that is, an increase in the rate of acceleration, which will be very decidedly preferable as regards the comfort of the passengers and as regards strain upon the draw-bar and transmitting mechanism. The restoration of energy by this system in stopping and upon down grades is perfect, and the restoration of energy may be made efficiently, not merely while the locomotive is at full speed but at any speed and at all speeds down to dead rest. The size of the motor generator and its weight are factors of importance,

and by many have been considered as fatal to the introduction of the system, but the economies and perfection of control which result from this variable speed ratio of electrical gearing are such that it has many advantages that may perhaps overcome the disadvantages that the motor generator gives. It may also be of interest for me to say that I have recently brought out and patented a system of multiple control which is adapted to this particular form of electric railway system, by which it will be possible to couple and control in a very simple manner any number of locomotive units from any desired point on the train and without the necessity of opening any motor circuits or having any resistance or automatic switches in the motor current. An advantage that this system will give, which is not so well reached with other systems, is a very perfect distribution of the tractive efforts at the various driving wheels, without any skidding difficulties such as are likely to result in the case of a series motor. There are a good many incidental advantages in connection with this system that are minor, but as this locomotive is now under construction and is likely to see service in the immediate future, the only thing I wish to call attention to now is the fact that results will be probably available from practice with this system shortly.

MR. HARRY ALEXANDER:—I would like to ask Mr. Arnold a question. I have in mind a mental photograph of the yards south of 56th street on the New York Central road. Has he got to the point where he has under consideration the breaking of the overhead construction line, owing to the multiplicity of tracks and the breaking of the circuit while the train is still under enormous starting currents? That is a problem of minor degree, but still of great importance.

MR. ARNOLD:—We do not break the current at all; we are supposed to have a continuous plate overhead in the yards.

MR. ALEXANDER:—I do not see how that is possible with all the crossings there, at each of which there must be a break in contact.

MR. ARNOLD:—Simply an upper-bearing contact shoe bearing against a continuous plate conductor.

MR. ALEXANDER:—You have a break on the surface third rails or conductor rails, at all rail crossings, and there must be a break of *contact* to some extent at least, even if the break in the conductor is bridged by a contact plate.

MR. ARNOLD:—When the working conductor is on the ground it is necessary to break it only to let the track rails through at switches and cross-overs, but I do not see the necessity of a break in the overhead rails; the working conductor is overhead and as there are no track rails overhead there is nothing in the way to prevent a continuous contact of the under running shoe.

MR. A. H. ARMSTRONG:—I do not want in any way to forestall the extemporaneous paper which Mr. Arnold has in his pocket; I know he is going to deliver it and that it is well worth listening

to, but the subject of alternating motors has been brought up and I want to discuss two or three points in connection with such motors. We are all interested in long-distance high-speed travel and have lately read in periodicals some partial results of very complete experiments made in Germany where the maximum speed reached 100 m.p.h. with single electric cars. The results of these experiments would seem to indicate that such work may be taken up by the electrical engineer with perfect assurance of success, provided, as has already been touched upon in this meeting, that a roadbed with sufficient carrying capacity is furnished. In fact, the problem becomes not an electrical one but rather one of mechanics, the providing of a car of sufficiently strong construction, wheels that will not fly to pieces at the speed contemplated, and, more than all, the providing of a roadbed capable of sustaining the tremendous shocks which a car at these high speeds is bound to deliver. All this has a bearing upon the subject of alternating railway motors. Very high speeds would hardly be contemplated for short distances, except, as Mr. Pearson pointed out, that such high maximum speeds might be used to reduce the running time on suburban systems where the traffic was enormous and where the running time between terminals was the all-essential point. High-speed roads, however, are essentially long-distance roads. Direct current is limited in the distance to which it can be transmitted economically, and a direct current generating station could not be considered for roads of this character. The problem thus necessitates consideration of alternating current either single-phase or multi-phase, and either converted to direct current or used with some form of alternating motor placed on the moving car. If alternating motors are used, the single phase is preferable and may or may not be of the ordinary induction type. The primary consideration is, however, the installation of some form of alternating motor upon the car, receiving alternating current over the trolley or third rail at potentials much higher than used at present, say 3,000 volts or even as high as 10,000 volts. As any further remarks that I have to make in this direction are of secondary importance to the bringing out of Mr. Arnold's paper, I resign the floor in his favor.

MR. POTTER:—As the paper which Mr. Arnold and I prepared relates particularly to the relative performances of the steam locomotive and motor car, I think in closing the discussion it might be well to point out, or rather to emphasize, the advantage of eliminating the dead weight of the locomotive in the consideration of apparatus for high-speed work, particularly the use of alternating current apparatus. It would seem to be specially advantageous that each car should carry by itself as little apparatus as possible. While beyond doubt single-phase current, transformed into polyphase or into direct current, would operate an electric locomotive of any form economically and would probably perform its service well, there would seem to be a decided advantage, where alternating line current was to be used,

that there should be as little motive power apparatus on the locomotive as possible other than the motors themselves, this applying equally whether the motors themselves are alternating or direct current. We have doubtless all looked forward to a single phase railway motor having the characteristic of the direct current series motor and operated from a single trolley, and I trust that study and development will ultimately produce such an equipment, but at present there is no simple and satisfactory motor or method of control. Three-phase railway motors have been and may readily be used, with certain limitations, but it seems hardly probable that the development of the art in connection with polyphase transmission will be other than the use of the least amount of apparatus that can be installed upon the car for the purpose.

There is one limitation that we must take into consideration. I have heard it stated that our standard gauge of 4 feet 8½ inches was established by a blacksmith in Albany, who was told to cut a 5-foot gauge for the Mohawk Railroad, but his rule slipped or something happened and he cut the bar 4 feet 8½ inches, and I believe that is the basis of our standard. It would well have served our purposes if he had cut it 6 feet long. The space provided between the wheels on the standard gauge does not afford the same possibilities in designing motors for installation on a car as for stationary use. In stationary apparatus we do not care whether a motor is just so many inches high or wide, whereas in designing a railway motor, of whatever type, very frequently in order to secure another eighth of an inch in clearance a complete redesigning of all the parts is necessary; we cannot change one element without changing many, so closely are the details laid out. The diameter of wheel, diameter of axle and length of wheel-base, all have an important bearing on the motor design. In this country there is a disposition to favor a short wheel-base. High speeds and the carrying of motors directly on the axle, require an axle of larger diameter than are commonly used on passenger coaches. That of itself takes part of the space, and I think it is a very serious handicap in the development of motors for railway work, that the wheel-base should be so generally limited to 6 feet. For motors of 100 h.p. or over, it is very desirable that the wheel-base should be at least 6½ feet. A 36-inch wheel would also be advantageous. A 6-foot wheel-base truck, does not permit the best design of motor of any character in large sizes nor does it allow the space for axle diameter and truck bolster that should be provided for heavy service.

PRESIDENT STEINMETZ:—Gentlemen, I now call on Mr. Arnold to conclude his paper by giving us his extemporaneous speech.

MR. ARNOLD:—First, before getting into my next subject, I want to voice my appreciation of the kind expressions that have been shown toward me here to-day both in words and actions, for this work on the New York Central, and I sincerely thank you. After all, there is no higher ambition that I know of for

any man in this world, than to be able to accomplish something as he goes along through it, and write a record of that work, where those who follow him may read it, and perhaps be benefited by it; for, although we do the best we can, the probability is that those who examine our work one hundred years from now will wonder at the crudity of our methods, for with Tennyson,

> "I doubt not through the ages one increasing purpose runs,
> And the thoughts of men are widened with the process of the suns."

In regard to Mr. Potter's blacksmith; to the credit of Mr. Potter, he is a somewhat younger man than I am, and he probably does not remember that the original gauge of some of the railroads of this country was 6 feet. I have ridden over the Erie Railroad when it was what is known in railroad parlance as a "6-foot gauge." The man who established that gauge must have lived prior to Mr. Potter's blacksmith; and the only unfortunate thing for electrical engineers of the present day is that Mr. Potter and Mr. Sprague and Mr. Edison and Mr. Steinmetz and a few other distinguished gentlemen, who have been instrumental in developing the electric railway, could not have lived at the time Mr. Potter's blacksmith re-established the gauge for he might have been dissuaded from narrowing it. Now as to the extemporaneous speech. I want to say that it was my intention to deliver what I might have to say on this subject, extemporaneously if it came up at all; but about two hours before my train left Chicago, through the advice of my patent attorney, who knows my weaknesses, I concluded to write my remarks, so I hurriedly dictated them to my stenographer, grabbed my valise and took the train, leaving my speech to be written out, and it reached me as I came into the hall this morning. With your permission I will read it now.

Mr. Arnold then read his address entitled "An Electro-Pneumatic Railway System."

[See page 659, May Issue].

PRESIDENT STEINMETZ:—I believe our INSTITUTE should be extremely grateful to Mr. Arnold, not only for contributing such a valuable paper as the one which he has just presented, but also for communicating to us his new ideas regarding alternating current railroading, and as Mr. Arnold communicates it at the close of his discussion, it shows that he does not desire a discussion thereon, which I fully agree with and appreciate, the more as he told us that his invention was approaching completion and actual results of operation would be forthcoming in a very short time. I hope and feel confident, considering the attachment Mr. Arnold has always shown for our INSTITUTE, that the results will be communicated for our discussion also. I will now call upon Mr. Mailloux to conclude the discussion on his paper.

MR. MAILLOUX:—Before passing on to my own paper, I would like to say a few words concerning the other papers; first in regard to Mr. Armstrong's paper. I have already commented in

my own paper in terms of admiration on Mr. Armstrong's work, as shown in his Omaha paper. I do not want you to think I am unduly prejudiced in favor of Mr. Armstrong, but I wish to speak in terms of admiration for his present paper. To me it is one of the most interesting papers. It represents the analysis of facts by the analysis of principles; and to me it is the type of a paper which is not only useful for present purposes, but is also useful as a stimulating influence tending to develop the application of principles to other less known purposes. I therefore feel that the INSTITUTE is to be congratulated for a second classical effort on the part of Mr. Armstrong.

I have very little to say about the very excellent papers of Mr. Potter and Mr. Arnold; except to congratulate them both on the excellence of their work. These papers really require no discussion. I wish especially to congratulate Mr. Arnold on the fact that he became somewhat " demagnetized " himself on the alternating current motor question. At the time of the Buffalo meeting he was undoubtedly studying a " theory," and I can understand now, after having heard his " extemporaneous " speech, what that " theory " was; but, as his paper shows, in dealing with the actual case, he found himself, to use the words of a famous national duck hunter, " confronted with a *condition* and not a *theory* " and therefore had to deal with the case in a practical way, by resorting to direct current motors, which was the only practical thing to do.

Coming to my own paper, I wish to thank Mr. Dodd for the kind remarks which he has made and for the high implied compliment contained in them. I appreciate it all the more since Mr. Dodd himself is a mathematician of no mean analytical skill and knowledge, and since he is thoroughly familiar with the discussion of these problems. I wish to thank Mr. Dodd on this occasion for many valuable suggestions I have received from him personally in the pleasant relations we have had during the last five years. I may state that I am no longer entirely discouraged of being able to find an analytical solution of the problem he has referred to. The paper which I presented to-day offers some clues which may lead later to a perfect analytical solution. Not being able to solve the problem analytically, I did the next best thing, and solved it graphically. If we can find an equation, analytical or empirical, which can give us first the train resistance as a function of the speed, second the tractive effort in terms of either speed or current, then the solution would be easy. I have not yet found the analytical solution, but it is possible we may be able to find an empirical equation, and this may lead to an analytical solution of the problem, which, while not theoretically perfect, would be still of great practical value and convenience, and would therefore result in a still further simplification of the plotting of time-function curves.

MR. F. A. PATTISON:—Mr. President, the ladies of the Thursday Morning Club have been very kind to us during our stay, and I have been asked to bring before the Convention a matter which I can probably present more properly by making a motion. I move that the Chair appoint a committee of three, for the purpose of obtaining from the members of the INSTITUTE a subscription, for a loving cup to be presented to the Thursday Morning Club.

[The motion was carried unanimously and the session adjourned.]

At 10 o'clock on the morning of June 19th, Dr. Arthur E. Kennelly lectured before the Thursday Morning Club and its guests, at Kellogg Hall on the subject of "Wireless Telegraphy."

At 4 o'clock in the afternoon the INSTITUTE was entertained at an Organ Recital at "Barrington House," with the compliments of Mr. Searles.

At the links of the Wyantenuck Golf Club in the afternoon, there was an open air concert, and light refreshments were served.

In the evening by invitation of the Thursday Morning Club, there was an Assembly at the Town Hall, participated in by the residents of Great Barrington and vicinity, and the members and guests of the INSTITUTE.

Discussion.

Papers by Percy H. Thomas, Miles Walker and Charles E. Skinner, at Great Barrington, June 20, 1902.

[See May Issue.]

Dr. Edward L. Nichols:—I should like to say in reference to this last paper, that in some recent observations by Dr. Shearer which were intended for quite a different purpose, that of studying the change of length of tubes subjected to electrostatic pressure either alternating or direct, our conclusions with reference to what took place were very similar to those described in this paper. It was found that before the breaking down of the dielectric, this heating effect was noticed, even in glass and rubber, making it exceedingly difficult to carry the tests up to the neighborhood of the breaking point. I should say that the observations which were made were entirely corroborative of the view just suggested; that the breaking down of the dielectric even where the stress is direct and not alternating, was to be ascribed to heating. It seemed to be a mechanical breaking down, due to the extreme local heating of the dielectric, but in no case a rupture traceable to the mechanical forces of the electrostatic field itself. I mention these observations because they were made with the direct electrostatic stress, and not with alternating potentials, and may serve therefore, to broaden and make more general the conclusion reached by the author of the paper to which we have just had the pleasure of listening.

Mr. Charles F. Hopewell:—I would like to ask whether the author has made any tests on underground cables.

Mr. Skinner:—I know of no test made directly for that purpose, but I think the results are entirely applicable to the insulation of such cables.

Mr. W. S. Andrews:—I should like to ask Mr. Skinner if he has ever noticed the effect of oil on mica, in the way of weakening its resistance to puncture. I once made some tests in this line and found that a sheet of mica which would resist a pressure of 10,000 volts for an unlimited time in air would break down almost instantly under oil at a pressure of 4,000 or 5,000 volts.

Mr. Skinner:—I have not made tests under oil, but I have done so with a film of oil on the surface of mica and found that to be the result.

Mr. W. S. Andrews (*Communicated after adjournment*):—The following tests were made with alternating current delivered at 118 volts, 60 cycles. The voltage was raised by a small step-up transformer with necessary regulating devices, and measured by a G. E. static voltmeter reading up to 10,000 volts. A good quality of clear white India mica was used, a dry sheet of which, .002″ thick, would stand a pressure of 8,000 volts for an indefinite time in air.

The accompanying sketch (Fig. 1) shows the general arrangement of the testing apparatus. A and B are two brass rods supported by a piece of hard rubber, C, and bent towards each other at right angles at their lower ends. One of these rods terminates in a brass disk about $\frac{3}{8}$" diameter and the other rod is finished with a rounded point touching in the center of ths disk. This rounded point rests against the disk with sufficient pressure to

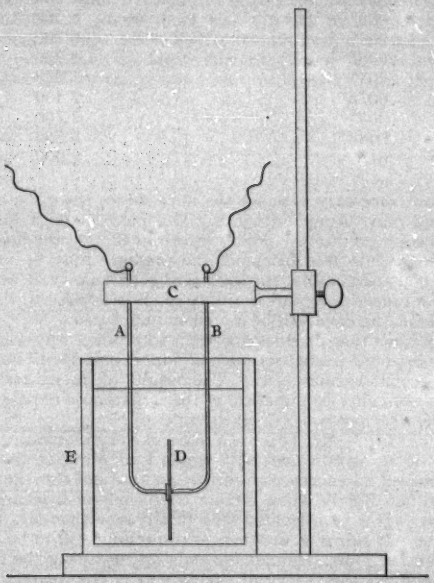


FIG. 1.

support the piece of mica, D, that is to be tested. These parts are attached to a stand so that the holder with mica may be lowered into a vessel, E, containing oil. Preliminary experiments were made with various kinds of oil, but no difference in results could be observed, so it was decided to use a good quality of transil oil for the present tests.

The figures in the following table show the average puncturing voltage derived from a number of tests made on each thickness of mica used.

THICKNESS OF MICA.	AVERAGE PUNCTURING VOLTAGE.
.001″	3,800
.0015″	4,500
.002″	4,600
.0025″	4,750
.003″	5,300
.004″	5,570
.00475″	5,950
.005″	6,050
.006″	6,700
.0065″	6,930
.007″	7,220
.0075″	7,400
.008″	7,700
.0085″	8,550
.01″	8,900

It is not necessary to place the mica under the oil in order to reduce its puncturing resistance. If a piece of mica, say .002″ thick, is supported in the holder shown in sketch, the holder and mica being quite free from oil, the pressure may be raised to about 8,000 volts, and, if the mica is of good quality, it will stand the strain indefinitely, but if a drop of oil is applied to the blunt metal point, the mica will be instantly punctured.

It is curious that oil does not seem to produce any weakening effect on artificial insulators, such as paper coated with boiled linseed oil, copal varnish, etc. The results of many tests show that the resistance to puncture of these materials remains about the same, whether tested in air or under oil.

DR. PERRINE:—Mr. Thomas's paper is very interesting to me. In some of the installations with which I am familiar, there have been installed an enormous number of gaps, and they have been found to fail utterly when certain conditions of discharge were produced. This is a decided step in advance that Mr. Thomas has made. It seems to me there is something still to be done in that direction. Mr. Thomas depends on rupturing the current, if I understand the theory of the paper, by the introduction of the shunt resistance in addition to the series resistance, and that means that the shunt and series resistance combined must be comparable to the total resistance of the circuit. It is possible to do that, but that amount of resistance may run up to a very large amount in many cases where we have in series with the generator a long-distance line in which the resistance has become considerable. Then there is another point that seems to me not to be covered by this particular device, and that is the fact of the change of frequency which occurs when the lightning arresters discharge, and the line is short-circuited through the lightning arresters. For power-house conditions I should be inclined to think that Mr. Thomas's plan would be applicable, because there

we have simply the inductance of the machine to take care of, and the resistance if made high enough will take care of every form of the charge, but when we put the same apparatus at the end of a long line or end of a heavy cable, we get entirely changed conditions. Mr. Thomas's paper is one of the most difficult to raise any points of objection to, because it is an experimental paper, and a man who has performed the experiments knows what his apparatus will do. At the same time I have had a recent remarkable instance of what I suppose is resonance in a cable line going into a substation where there was a break in the wire in the cable, opening only after high currents began to pass. The cable was closed, and moderate currents flowed. When large currents began to flow there was an arc produced within the cable,

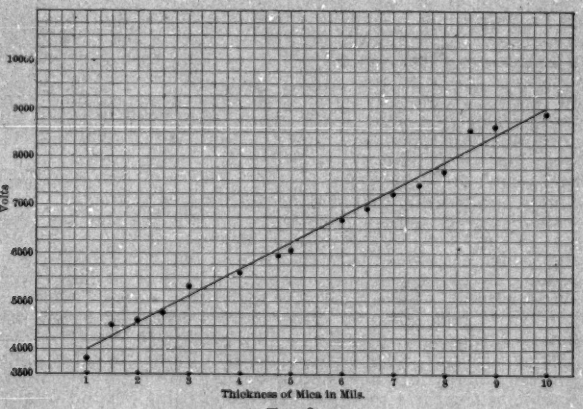


FIG. 2.

and the effect of that was to let such currents through, that the fuses were blown out and fuse blocks destroyed, and switchboards blown out, and an appearance of short-circuited currents entirely beyond the capacity of the machine to produce. If the self-induction of the machine had not been counteracted by the capacity of the cable that is producing this resonant condition, by reason of the fact that the arc was of an immensely higher rate of alternations than the normal rate of alternations of the machine, allowing currents to flow by, putting the line in the condition of being for those frequencies practically distortionless. I should think the same effect would be found in producing an arc between the gaps of an arrester at the terminal of a long line, or where we had long cables. This can hardly be overcome by any ordinary value of non-inductive resistance, and it might be

necessary to carry on this work a step further, using possibly a number of selective resistances, some of which would stop the normal rate of frequency, and others would be resistances when the frequencies were very much increased. That is a condition that we are likely to meet in all lines where we have large capacity in series with generating apparatus or other apparatus where the inductances are large; and whether the arc is of true alternating character in the small gaps of a lightning arrester, I don't know; but if it is of that nature, we undoubtedly would have under certain circumstances the induction of the circuit; and I would be inclined to think that in such circumstances these arresters will not act, and until this system has been thoroughly applied to such cases, I think it will be impossible to say that the result that Mr. Thomas has reached is the complete solution.

Regarding Mr. Skinner's paper, I notice in the curves on Figs. 2 and 4 a remarkable resemblance to similar curves that have been derived from high-potential tests of long cables, and particularly with the curves that are derived in working with gutta-percha at varying temperatures. The energy loss at varying voltage and varying temperature seems to be, from the appearance of the curves, almost the same as the character of curve which is obtained with gutta-percha. Now the work with cables has also shown the correctness of Mr. Skinner's observations, that a slight amount of moisture in the insulation will materially increase the heating, and that heating of this character almost invariably results in final breakdown; and the fact that the heating is greater than the $C^2 R$ loss, has also been observed in cables, and my idea has always been that that is due to electrolytic conduction. In experiments with cables that are at all damp, with a direct current, I have invariably found that where a cable was subjected to high-potential direct-current strain, and then disconnected, that cable acting as a storage battery would furnish a current for a very considerable length of time. In cable working I found many instances similar to that, and invariably where I found the temperature of the insulation rising beyond what it should attain, due to the strain from the potential applied, that it was due to the presence of moisture, that there was a distinct appearance of electrolytic conduction through the cable, heating it more than would be reasonable to suppose, and ultimately breaking it down. Mr. Newbury, the electrician of the Roeblings, has also found a number of interesting things in connection with thoroughly dry cables. His experiments seem to indicate that with fibre cables you can increase the dielectric strength of the cable by increasing the thickness of the insulation, up to a certain critical e.m.f.; beyond that point the cable seems to break down at almost the same potential, irrespective of increase in thickness; and in discussion with him I came to the conclusion that it was impossible to so thoroughly saturate the fibre cable that there are no vacuous spaces in the insulation, and in certain cases those vacuous spaces distinctly acted as a conductor,

and beyond those potentials it was not possible to use that type of insulation. The same thing we generally found in breaking down rubber cables; that in nearly all instances where the rubber cable was broken down below the normal e.m.f., which should break the dielectric, that there were vacuous spaces within the rubber, not necessarily any moisture present, but simply rarefied gas. Through vulcanization of the cable the air would be heated, a small bubble of air would increase to a large one, the rubber became vulcanized, and would not contract when the temperature was relieved, and that would make a vacuous space which would invariably locate the breakdown of the cable at and below the normal dielectric strength represented by the thickness of the insulation and character of the material; and it seems to me that this work of Mr. Skinner's has shown very clearly that for perfect insulations we can gather a great deal of valuable information by comparing the work that has been done by the cable engineers in the very careful study which they have made of gutta-percha. Vulcanized rubber has never been studied so carefully, at any rate studies have not been published, because vulcanized rubber is such an indefinite material; but gutta-percha is a perfectly definite material, has been carefully studied, and seems to bring out an entire confirmation of the class of results that Mr. Skinner has brought before us.

PROF. THOMSON:—I am inclined to agree with Dr. Perrine with regard to the necessity for carrying out tests concerning lightning protection under practical conditions; that is, we must gain our experience not so much in the laboratory with limited appliances, but with our lines. We must look for damage on or from the actual lines, see what caused it, and then attempt to find the remedy. We can, of course, reproduce to a certain extent the conditions by laboratory operations, but when we have a long line with capacity and inductance to take into account, and high potentials in operation, the conditions seem to change the results very materially. In regard to the point which Dr. Perrine drew attention to, the insulation breaking down notwithstanding the increase of thickness, I think there exists a very simple explanation for that. Given the diameter of the wire of the cable, a certain thickness of dielectric surrounding the same, it is manifest that the stress is a radial stress, and most highly concentrated around the wire, and so an increase of thickness may not change the radial stress particularly. It is akin to the fact that with a certain diameter of wire in the air under electrification up to a certain point, the air breaks down near the wire. There is a blue discharge over the wire in the air at certain potentials. The only remedy is to increase the diameter of your metallic portion so as to reduce the gradient of stress, reduce the steepness of the gradient at the wire surface.

DR. PERRINE:—I do not think that explains it altogether, for the reason that experiments were made with wires not smaller than $\frac{1}{4}''$ in diameter. While that is altogether true, it does not

seem we are getting up to the point or condition with a ¼" wire and 10,000 volts strain.

PROF. THOMSON:—I agree that it undoubtedly is provoked by some lack of homogeneous character in the dielectric; but my point is you do not gain such a great deal by the addition to thickness; that the stresses remain high on those weak points. In the same way, the mica plate being broken down when covered with oil or an oil film, the tendency there is, the oil being thick and thin in spots, to produce again the radial stress upon the thin portion—the concentration of stress will be at the portion where there is no oil, or at least where the oil may be the thinnest, and there is protection of the surrounding area by the layer of oil.

DR. PERRINE:—That is invariably true with any compound dielectric.

MR. THOMSON:—Yes, it is undoubtedly.

MR. MAILLOUX:—It was pointed out in a paper read before the Institution of Electrical Engineers in London by Mr. O'Gorman, that sometimes a piece of very highly insulating material placed between two conductors subjected to a high e.m.f. would, instead of increasing the resistance to puncture, actually decrease it. The explanation given in that paper is that a piece of glass, for instance, while it is a high insulator, yet is really a lower insulator than dry air, and consequently it tends to really increase the difference of potential across the actual air gap remaining; in other words, if there be no glass, we have a certain fall of potential between the two points, but if we put a piece of glass there, which really acts as a high resistance conductor, the effect is the same as if the actual difference of potential were increased. This may perhaps have some relation to the question here discussed.

There is another point upon which I would like to have some information. I had occasion some five years ago to make some experimental tests in a rough way of a certain insulating material. The experiments were conducted at a laboratory in Vienna by Professor E. Grau and myself. The material was a sort of resinous compound which became soft at a certain temperature. This material was placed in thin sheets between two discharge points, connected with a Holtz machine, using a by-pass spark gap of lower potential in the well-known way, so as to control the voltage applied to the sheet of material at the point to be tested. Although the temperature at which this material resisted puncture was quite high, it was observed that in every case before the puncture took place there seemed to have been a thinning action, as if the material was mechanically brushed off radially from the point of greatest stress, and pushed away on each side, the action being quite similar to the displacement or the flow of metal by the action of a die—or other perforating instrument—when we try to perforate a piece of lead with an awl for instance, when the metal flows or is displaced sidewise. There seems to have occurred an action, quite similar and comparable to this; and the

conclusion which Professor Grau and I came to, at the time, was that the puncture resulted not only from the increase of temperature, and the consequent actual decrease of the dielectric strength, but also from the actual thinning of the plate. In some cases a thinning in a plate of three or four millimetres thickness occurred to the amount of as much as half a millimetre before the puncture took place. I would like to know whether any similar effects have ever been observed in any other materials which are not viscous, at such low temperature. I think that in any homogeneous substance which becomes softer as the temperature increases, we should have an analogous phenomenon. In this case, the phenomenon seemed to be more of a mechanical character, than of a chemical, electrolytic or other similar nature.

MR. THOMAS:—I would like to make one point in regard to Mr. Skinner's paper. His conclusions are specially valuable as they represent the results of a number of years of practical commercial work, and of a great many tests made under a great many different conditions, a great many different times, by different people and different methods, and the conclusions from all those tests are summed up and brought into a general law. There has been a great deal published in a fragmentary way on this subject by men who have tested a few samples, may be a good many samples of one particular object; and taken all together, something can be derived from these results; but they are not to be compared with the results which are obtained by Mr. Skinner by years of experimenting on practical materials, under working conditions. I would like to bring out one point relating to the continuation of Professor Thomson's discussion in regard to the breakdown of these cables. I think it was Mr. O'Gorman in a recent paper before the British Institution who stated that a cable can be made with materials of different conductive capacity placed on different circles around the core and in this way the strain can be made equal on the outer portion or the inner portion.

MR. WM. MAVER, JR.:—In regard to the point raised by Dr. Perrine, that the pressure resisting quality of the cable does not continue to increase with the thickness of the insulating material, I have heard the explanation offered that it may be due to the fact that, as we all know—I presume the Doctor has referred to oil saturated cables—it is necessary in these fibrous cables to expel the moisture very thoroughly, and to do that the cables are dried in a heating oven, and it has been observed that when the insulation exceeds a certain thickness the amount of heat necessary to drive out the moisture is so great or so long continued that it has a detrimental effect upon the outer layers of the insulating material; and on the other hand, when the cables are then plunged into the insulating compound, the thickness of the material does not permit the oil to permeate the entire mass of the fibrous material, and therefore its dielectric strength is not

so great as might be expected in proportion to the thickness of the insulating wall.

PROF. P. B. WOODWORTH:—I have found when the dielectric strength was very low, a transformer placed in circuit would break down. I tried to account for this condition, by using commercial oil where I obtained a dielectric strength of about 16, put it into a transformer and found a dielectric strength of 2. I carried on quite a series of investigations, tried to find out why the oil dropped from 16 to 2, and for a long time could find no clue to it. I came to the conclusion that there was enough water in the transformer at the time the oil was put in, to furnish sufficient moisture to diminish the dielectric strength. I tried some experiments, and found all I needed was something less than 9/100 of 1 per cent. of water in the transformer oil to change the dielectric strength from 16 to 2. The oil used in the transformer was regular commercial oil. I then carried on some investigations to ascertain where the water came from. I made some calculations as to the amount of moisture there was in the air at the place, and the amount of change in the temperature that would be necessary to form a deposit in the transformer sufficient to supply all the water required. I found a change of temperature of about 10°C. was all that was necessary to form the film on the plates in the transformer, sufficient to change the dielectric strength. It seemed to me, when the transformer is sent out to be filled with oil, great care should be taken that the transformer is warmed up before the oil is sealed in; the immense surface permits a deposit of moisture.

PRESIDENT STEINMETZ:—I can corroborate the statement that the disruptive strength of oil is very largely affected by a trace of water. That is one of the most important matters where oil is used for high-grade insulation. If there is no further discussion, I call upon Mr. Thomas to conclude his paper.

MR. THOMAS:—I have only a few words to say, though the subject might be discussed almost indefinitely. It is very true, as President Steinmetz, Professor Thomson and Dr. Perrine stated, that experiments with trial plants of large capacity is the only certain way of determining the full effect of any such apparatus. It may turn out there is a difference on whichever end of the line the arresters are placed. In any case, however, we are to look for favorable results as regards oscillations from the use of resistance, for though the resistance may not always be sufficiently great to overcome all tendency of a circuit to oscillate, yet it is in the right direction and at least as regards resonance phenomena, we are better off with it than without it. I feel sure, however, that our troubles will not be increased even on the largest lines and highest voltages, by the presence of the arresters, provided they are properly designed.

In regard to one of the points our President brought out I will say that I should have made it clear myself that we have as a result of using the series and shunt resistances, double the num-

ber of gaps to suppress the generator arc. This principle can theoretically be carried further; if we have three times the number of gaps necessary to withhold normal voltage, the second part shunted by a high resistance and the third by a low resistance, we can without increasing the voltage necessary to cause discharge, have three times as many gaps effective as with plain series resistance, and so on. Practically, however, such an arrangement involves rather too much complication.

The discussion on Mr. Skinner's paper suggests a point that I wish to bring out. Very possibly the energy loss in commercial insulating material is due to local high-resistance conduction within the material. If this is true, we should not expect the law that a single cycle has always the same loss of energy in it to hold strictly, independent of frequency. For if we assume local high resistance conductors in the midst of the material, we can analyze the phenomena in this manner; if the local circuits were perfect conductors, they would have the effect of reducing the thickness of the dielectric; if perfect insulators, they would have no effect at all, but as they are somewhere between perfect conductors and perfect insulators, their effect will be intermediate. When the frequency is very low, there will be ample time for all necessary charge to flow through the high local resistances so that it acts nearly as a perfect conductor. If, however, the alternations are very rapid, and a high internal resistance will not allow time for any appreciable charge to flow, then the result would be that local circuits will act nearly as perfect insulators. There will be a certain $C^2 R$ loss in either case, and a difference in the effective thickness of material, so that frequency will evidently have a very decided effect on the energy loss per cycle. Experimentally it is found that differences in temperature, differences in frequency, differences in amount of moisture, etc., affect very materially the loss per cycle.

It is very desirable, of course, that we learn how to build dielectric material perfectly homogeneous and in the very best possible condition electrically, but we must always bear in mind the fact that even though this ideal is attained, it will be very difficult to maintain; the material must be carefully protected, so that no moisture or other harmful matter can be absorbed. The difficulty of maintaining the ideal condition in commercial practice may prevent our making full use of a perfect dielectric, even if we are enabled to produce one.

MR. SKINNER:—I have but a word to say further about Mr. Walker's paper, and that is this, that the author considers, I believe, the chief points in the paper the simple method he has given for calculating the torque on the needle and the elimination of the A^2 term in the formula.

In regard to my own paper, I may say that while the investigation of a theoretically perfect insulator is of very great interest, it has been of infinitely more importance to us to take the insulating materials that we are compelled to use in actual practice, and to

determine their characteristics, and to find out just how they would act under normal operating conditions. In regard to the point raised by Mr. Mailloux, I may say that I have frequently noted an actual mechanical rupture, principally in connection with some tests of glass under oil. In some instances I found actual chipping of the glass to such an extent that pieces as large as pin heads were scattered over the surface of the glass and a groove was cut, in one instance, half way through a piece of glass which formed one of three or four placed together. This was undoubtedly due to mechanical action.

In regard to the question of water in oil, I may say that this may be detected either by measuring the actual energy loss in the oil or by measuring the dielectric strength. We have found that heating almost any commercial oil increases its dielectric strength. This results until the oil is heated almost to the charring point.

PRESIDENT STEINMETZ:—Gentlemen, before proceeding to the reading of the further papers on to-day's progress I call upon Dr. Kennelly, the Secretary of the Committee on Standardization to submit to us the report of this Committee.

DR. KENNELLY:—The report submitted by this Committee, of which Prof. Crocker is Chairman, differs from the report which was adopted by the INSTITUTE in 1899, mainly in the direction of different paragraphs. A few changes have been made in the report as it was submitted originally, but the principal points of interest are the additions which have been made. I will just run over the report briefly and point out the salient features of addition. A few definitions have been added on the second page.

[See page 705, May issue.]

DISCUSSION.

PRESIDENT STEINMETZ:—Gentlemen, as you know, the Committee on Standardization has been working very hard for about two years in amending and adding to this report. It has been submitted to a number of prominent engineers to obtain their opinions, has been reconsidered and finally submitted to the Board of Directors, and by them ordered to be printed and submitted for final action by this Annual Convention. It is left to you, then, to say what action you care to take. Discussion on the report is now in order.

[The report was discussed by Prof. Owens, President Steinmetz, Dr. Kennelly, Prof. Adams, Mr. Lieb, Dr. Matthews, Dr. Nichols, Mr. Rice, Prof. Thomson and Mr. Hering.]

DR. PERRINE:—I think our committee has worked very faithfully and presented a very able report, and I therefore move that the report be received and adopted.

PRESIDENT STEINMETZ:—I should like to make the amendment that the report be adopted as a whole and that Sections 71 and 42, the two paragraphs regarding which serious objections have been raised, should be referred back to the Committee on Standardization, with power to amend if they see fit.

MR. STANLEY:—I heartily endorse the suggestion made by Mr. Lieb regarding a definition of what constitutes a proper and satisfactory meter. It does not seem to me that that question ought to be left to irresponsible people to decide; it ought to be taken up by men who are competent to carefully analyze the subject, and a proper and careful report made on it. It reminds me of the definition which I heard the late Mr. Franklin Pope made of electric machinery—there were just two kinds, ours and the other fellows'; and I think that is about the status of the meter subject to-day. There are so many minor points to be considered in answering the question of what constitutes a good meter, that it really takes considerable time and study to place the subject clearly before one's self, and I hope that this Committee will give it thought and consult authorities on the subject before they finally make a report.

The amendment was accepted and the motion was then carried.

By permission of President Steinmetz, Prof. Robert B. Owens was given the floor to extend in behalf of McGill University an invitation to hold the next Annual Convention in Montreal. Prof. Owens added that it was proposed, also, to invite the Institution of Electrical Engineers to hold its meeting there at the same time, and make it a joint convention. After remarks by President Steinmetz, Prof. Thomson, Mr. Hering, Mr. Mailloux and Mr. Sachs, the invitation was upon motion of Mr. Rice referred to the Committee on Papers.

A paper on the "Determination of Alternator Characteristics" by Prof. L. A. Herdt was then read by Prof. Owens.

[See p. 723, May issue.]

DISCUSSION.

DR. PERRINE:—I am sorry that Dr. Kennelly is not here for he he has tested and applied this method of determining regulation by the e.m.f., which is, as I understand it, what is meant by the wording of Rule 71, to machines of the Stanley design. I mention this simply because I see from Fig. 23 that the machine in question, the inductor machine, is of the general Stanley design. It is, however, a design I have never heard of, and I presume was built by the Royal Electric Company, especially for McGill University. I know there has never been such a machine built in this country. The method that was shown by Prof. Owens is the method I know Dr. Kennelly has commonly employed for some time in predetermining alternator characteristics and he has applied it as well to commercial inductor alternators, as to revolving field alternators. Where the machine is a commercial machine I do not believe that the variation between the two curves will be noticeable. This particular machine is not a commercal machine; I know nothing about it. It happens to be about one-fifth the size of the smallest inductor alternator ever built of this type in this country and is probably a very remarkable machine.

A paper on "A New Current Tracing Instrument" was then read by Prof. Robert B. Owens.

[See p. 753 May issue.]

PRESIDENT STEINMETZ:—We have listened to a very interesting paper, and I am only sorry that the time is so short we will be unable to properly review and discuss it. If there is no further discussion, a motion to adjourn will be in order. Before calling for that motion, however, I may say there are two more papers—two of to-day's papers left over for to-morrow, and to-morrow is the last session, and we will have a discussion on a question which is extremely important. I shall, therefore, be obliged to call the meeting to order sharply at nine o'clock to-morrow.

On motion duly seconded and carried, the session then adjourned.

Friday afternoon a special train was provided by the Stanley Electric Manufacturing Company, by which the members were enabled to visit their Pittsfield works, twenty-five miles from Great Barrington. Those who preferred were entertained with a Tally-ho drive around Lake Onota, and all reassembled at a lawn party as the guests of Dr. and Mrs. F. A. C. Perrine, at their beautiful home. In the evening the members were the guests of the City of Pittsfield, and were entertained at the "Maplewood" by Mayor England and the Board of Aldermen, returning to Great Barrington at 10 o'clock.

DISCUSSION.

Papers by President Charles P. Steinmetz, Dr. Samuel Sheldon, Prof. R. B. Owens, Prof. William Esty, Mr. Harold W. Buck, and Mr. R. B. Raymond, at Great Barrington, Mass., June 21, 1902.

PRESIDENT STEINMETZ:—Gentlemen, the papers announced regarding the education of electrical engineers have been concluded, and discussion is in order. We have here an assembly of the most prominent electrical engineers from various parts of the country; from educational institutions, from manufacturing companies and from the field on consulting engineers, so we may expect a very interesting discussion which I call upon Dr. Perrine to open.

DR. PERRINE:—Our President asked me about three weeks ago to write a paper upon the subject under discussion. As I have been trying to make up my mind on the subject for seven years and trying to write such a paper for seven years, I came to the conclusion I could not do it in two weeks. In looking over all the papers this morning, it seems to me that all, except possibly that of our President, attack the problem from essentially the wrong principle. The authors have taken up the question of what shall benefit the electrical engineer. I think that the electrical engineer's training and technical training in general should not be taken from the view of the technique at all; I go back to the old school man who invented a word, applied to certain studies and called them the "humanities." He builded better than he knew, because while he meant Latin and Greek by "humanities," he expressed the studies that the world is interested in. To-day the studies that the world is interested in, the humanities, are the sciences, and in the concrete form the sciences are engineering. Now, then, I think that our problem is not the training of the technical engineer, but is the education of the man, and that should be our fundamental principle; consequently I think that the college should be a place where the man is grounded, and the tcehnical education should belong only to the post-graduate school. In my own experience I have had a remarkably fortunate training. I was first trained in academical knowledge and in my two post-graduate years I went into the laboratory where we had a man who could teach, and as apparatus we had two tangent galvanometers and one Thomson reflecting galvanometer without a shunt. When I began to teach I found that we had between the physics department and my own $2,500 and three old motors. Such conditions made me necessarily study the importance of the laboratory work, on which much stress has been laid here to-day, and I have come to the conclusion in my work and in the results I have seen from my men, that the laboratory work needed in college, is the work that is devoted to the fundamental principles and not to the technical training in particular. There is far too little physics; there is

far too little of fundamental mathematics; there is far too little of chemistry and other essential branches. In all of our technical colleges, physics is taught from one point of view, and a man is taken out of the physics course as rapidly as possible, and put into technical studies where physics is used from another point of view. The study of electricity and magnetism in the physics course begins with pith balls and works up historically, logically, only because it is historical; and the minute you get to engineering problems, you have to begin from the energy standpoint, which is an entirely different standpoint. This illustrates one of the deficiencies of the connection between our technical courses and our science courses. Primarily, a technical student should be a scientific man. In getting out from under the miasmatic influences of the church, we have forgotten very often, true religion, and we have forgotten that one phrase in the Lord's Prayer "Give us this day our daily bread," and I want to emphasize the word "give." We have forgotten that to a man who does his best work, whether he lives or dies for it, his daily bread is given; and we all think that we cannot rely on that Lord to give us our bread, but we have got to earn it; and so the technical student comes in and says, "How can I earn the most money." He is not a scientific man; he does not feel that the first thing for him to know is to know the truth and to be square with himself and square with the facts, and try the hardest to find out the essential facts; he tries in preference—and the college professor is usually to blame for allowing him to so try—he tries to get a bundle of facts in his mind which are similar to the tools in the box of a machinist that will enable him to earn a salary. In one electrical engineering college in this country the teaching is done almost entirely by illustrating before the student the types of apparatus that are made by the various manufacturing concerns in all their details; the professor begs, borrows or steals blue prints, has them reduced to lantern slides, shows them to the student and gives them copies. One told me with pride that the General Electric Company sent out in the wild woods some apparatus, and the drawings did not go with the machinery, and one of his men looked among his college blue prints and saw where all the bolt holes went and put that machine in place. Now, that is the extreme of that sort of thing; and there is entirely too much of it; there is entirely too much of the idea that you must teach a man that with which he can get a position. You should not teach a man how to get a position, but how to hold that position. Now, as regards the laboratory work, I congratulate Professor Owens on having money enough to build that laboratory; but if I had to use the laboratory, I would not know what to do with it. You can teach a man in that laboratory how every different type of machine is designed and how it is tested and everything of that sort; but a man can learn ten times as much who devotes six months of his first year in the laboratory finding out what is the resistance of a wire in every

conceivable way. When a man has once measured the resistance of a wire in every way that resistance can be measured, and when he has a piece of wire three feet long, to the resistance of which he can swear, he has learned about one-half of the measurements in electrical engineering, and he needs to study one or two machines, as our President says, so that he can go back to the principles of design and understand what the principles of design are; but to test and work up the idiosyncracies of an old Brush machine or this, that or the other machine, I do not think it is valuable. Neither do I think it is valuable to have the wires run for him; that is valuable in a research laboratory where you do not want to waste a man's time, but to have a college equipped in a way that is far better than any of the laboratories of the engineering establishments where a man would have to work, I think is putting things too readily into the hands of a student. I remember a number of years ago a discussion of this point in connection with some of the work in England. The English *Electrician* had a sketch of the boy dropping into lunch with his father, and his father saying, " where have you been this morning ? " " Well, I have been out to college and have obtained the mechanical equivalent of heat, and had a cricket game." And I am glad to see that Prof. Owens whom I am criticizing here, has not gone to the extent of laying out boards with punched spaces on, showing where each instrument is to go for each particular test that he is to call for; there are a number of colleges where pre-arrangement is carried to that extreme now. A man given all these helps does not know how to handle work; he does not know the essential principles of handling work; but if a man knows how to measure things, when he comes to measure a dynamo, he can do it just as well as he can measure anything else; and the measuring of a dynamo is no different from measuring any other piece of apparatus. He wants to know how to get self-inductions and what they are and how to get resistance and what resistances are, and so on with all the various measurements. He wants every one of those, and every college should be equipped with a research laboratory where everything is at the hands of the man who is sufficiently far advanced to go into research; but I do not think the freshman student wants to be put in the position of the research student nor be allowed to go within a thousand feet of the research laboratory. Another thing, I want to criticise is the college professor, nearly every one of them. In the first place, I think that a man has an everlasting and unlimited nerve who starts in to teach students who has not been a practical engineer. Again, I think that every man who is teaching students should find out what the world is doing, not by listening to engineering discussions in the societies—do that, by all means; not by getting such blue prints as his friends will give him—do that by all means, too; but not less than once in five years, and preferably once in three years he ought to spend a year in practical work, and I think that every college professor

in this land ought to get himself so close to practical work that practical men will be glad to have him in their establishments for a year. I know lots of these fellows before me here to-day that I would be tickled to death to get, even though I could not keep them, and that is the way the college professor could keep up to the times. We cannot expect books to be published fast enough to show how this rapidly changing art is varying, because the men that are doing the work are too busy to write the books; and furthermore, the books are written by men who have been trained in these technical courses where there are no techniques, and do not know a fundamental machine, so, when they discuss a machine they do not discuss its fundamentals, but describe its wheels; consequently, our text-books suffer as well as our educational courses and our students suffer from lack of fundamental principles. I am glad to hear President Steinmetz bring up the question of examinations. It has always been a hobby of mine that examinations have no place or use in a university, as they are ordinarily carried out. I do believe that once a year, the students should know that he is to be examined; and I believe that the professor who enables the student to get a line on the kind of examination he is going to give is playing into their hands and doing less than educating them. I believe first that an examination should be given because no man knows who has not done it, the value to a student of being compelled in three nights to review a whole subject. Then, when you come to the examination, my practice has always been and I believe it is right, to give three or four questions and ask the students kindly not to consult with each other, but to consult with all the books they can find in all the libraries in the country, and bring the answers in in about a week; and that sort of an examination calls for a review and it enables one to know whether a man has learned that subject or not. I had a great deal of trouble at Stanford, with one of the mathematics faculty. I wanted to give a course in differential equations. There was no such course there. I went to the mathematics faculty and finally got one fellow who said he would do it, but he added, "your course is wrong." I went back to the men and told them I had obtained the course. They said they knew that fellow and would not take it from him. Finally I said, "You put me in an embarrassing position; I have got this course for you." They consulted and came to me and said, "If you will guarantee that that man won't grade us and won't mark us at all, we will take the course," and there was never a more valuable course for my students and there was not an examination or anything connected with it; each man studied it because he saw in the work that I was giving them where there was the application. Now, I had rather see a college equipped with no laboratory at all and where mathematics is taught to its limit and where electricity and magnetism are taught to their limit, a college where chemistry is taught and where molecular

physics is taught and mathematical physics is taught, than a college equipped with wonderful laboratories where men spend their time in learning things they can learn better in the first mechanical institution they get into. The suggestion was made by Mr. Raymond that men work in machine shops during their vacation is admirable, provided the men can get such a job. I understand that is one advantage that the Lehigh students have: I don't know whether it is true now, but in the old days the Bethlehem Iron Works used to take all the students who would apply in the summer. That is the sort of thing I believe in. Another thing that was inaugurated years ago at Lehigh that I believe in—I don't know whether it exists there now or not—Professor McMullen who is now at Princeton, inaugurated the course of going through shops, studying machines, making drawings from memory and then dimensioning the parts and correcting the drawings. That trains a man's eye, so that when he sees a machine he really sees that machine and knows what it is. That sort of training is ten times more valuable than shop training. He will get shop training better in six months in a practical shop than in four years in a college. These things I feel very strongly, and I feel that the men that are being trained in the colleges are being given too much of that which shows; it is due to the fact, as President Steinmetz says, that there is competition between the colleges; it is just as sharp as any competition that exists in trade, and it is moulding a great many of our courses. The colleges like to bring the parents of a prospective student into a gorgeous laboratory and have them see belts whizzing and all that. It is acting as an injury to the men; they are not coming out with the same course in physics and the same understanding of everything in physics, not simply electricity, but also light, heat and chemistry; it is now a part of the business and so I go back to the essential training as a scientific man; but I do not agree with the idea that literary training is to be left out altogether. Our best scientific thinkers in the world have been men who have been strong in literary work. And there is another thing that we must think of, too, and that is that a man earns his daily bread here in this country to live, and not to earn money; and a man without literary training is only able to live outside of his profession, in the novel of the present day. So I feel that a man needs a strong literary training, a strong scientific training and a strong technical training, so that he is not absolutely ignorant of that side of the work when he goes out into the world.

MR. RAYMOND:—I would like to hear Dr. Perrine state his opinion as to the study of French and German.

DR. PERRINE:—Only as literature. I studied Latin and Greek for four or six years; I never could say I could translate a page of anything except some of the exceedingly easy things, but it did me an immense amount of good, because I got into literature, the grounding of the language. I think our President expressed

that perfectly when he spoke of English being taught by the philologists; we don't want philology, we want literature, and it doesn't make any difference whether it is in French or German; whatever a man can learn; if a fellow can learn and appreciate French and German, let him do it, and Latin and Greek; but if he cannot appreciate a foreign language, let him take English; he will get the same training in literature from them all.

PROF. MORGAN BROOKS:—May I call attention to the substantial agreement of Dr. Perrine's remarks with Mr. Esty's paper, although Dr. Perrine said that he disagreed with everybody except the President. With regard to the value of language study, knowledge of at least one foreign language, be it French, German or Chinese, is desirable from showing that other nationalities have quite different points of view from our own; and further, I believe that having obtained the idea of a foreign language, one would, for instance, go to the Philippines and learn Spanish much easier than if he had previously acquired no foreign language at all. The training of the imagination—ability to form mental pictures—developed by such studies as geometry, is also of great value. I should say that the new proposition of Mr. Arnold's regarding electro-pneumatic devices, requires for its production an amount of imagination not given by strictly technical education. Almost any thorough knowledge proves useful in unexpected ways. A general education gives not only ability of expressing one's self clearly, but affords a sense of proportion, the relation of technical affairs to those non-technical. Add to this a knowledge of men, and the engineer is better able to explain, say to the directors of a corporation, the strictly technical points of some proposition upon which his advice has been sought.

MR. STANLEY:—There seems to be a good many expressions of opinion as to the training an engineer should have, and those opinions are very divergent. We are called upon to study the kind of course, the kind of training, that a man who expects to follow the engineering profession should take. I say "expects" advisedly, because he probably goes to college, to the technical school, for the reason that he has seen some friend who has had that line of training engaged in that line of work, whose course he wishes to follow. I disagree most heartily, most thoroughly, with Mr. Raymond's notion of the education for such a man. It seems to me that you thus take away from him nearly all the pleasures of life. In the first place you restrict him to that sort of duty that a soldier follows; he is to be trained to do a certain number of duties, and do those without mistake. If we are to limit the engineering profession to those men who can only do certain mechanical or engineering or electrical duties in a certain way, then we must take from it all the men who are to carry the burdens of the future, to solve the problems that are coming on. There can be no inventors, because there can be no imagination developed by this course of training; and it seems to me that we

restrict our engineering work to its very narrowest limits. But there was one significant occurrence this morning that seems to be a final answer to this question: Every paper that was read this morning on this subject was presented by a man who did **not** have such an education; it would have been utterly impossible for the papers that were read this morning to have been prepared, and to express therein the sentiments and the views which they gave, if the men who presented them had had this limited, mechanically devised system of education; it could not be. I agree with Dr. Perrine in nearly everything that he said, and would point out that the men who are really relied on for the work of the world, are not men who are trained and directed and steered and personally conducted every moment through a college course. These cannot think; not on them must we rely, but on the men who are inspired by the work that is about them, inspired by the work that has been done in the past, and inspired by the hope that they may take some part in the work of the future; on this class of men this country and all the countries of the world and this profession and all other kindred professions must rely to bear the great burdens that are before us.

PROF. W. E. GOLDSBOROUGH:—I have been very much interested, very much impressed by what has happened this morning. I think that if I could have the men that Mr. Raymond has pointed out we should have, if I could have a class—say of thirty men—such as he has said we ought to have, I could develop them into engineers that would make the world fairly buzz; but we do not get that kind of men; we have just the ordinary young men that come to us. These we must train; these we must put in a way to serve their country and their fellow men. You gentlemen can tell us about the ideal way of training a man. Dr. Perrine has told us about the way a man should be trained, and I agree with him heartily. If a man has the time and has the money and has the ability, that is the training he should have; that is the training I want to give him, *but it is often impossible.*

Often a man has to take a training which is crude, which we know is crude, but which is best adapted for him because he has not the money or the time to spend for a better one. He may not even have the mental capacity for a better training. Nevertheless, we put him in a way to earn a good living, to enjoy himself in life, and to be of value in the engineering world; and this is accomplished without the necessity of his going through the work in the very highly thorough way which some of the gentlemen have mentioned, but which is impossible to about 50 per cent. or more than that of the men whom we get. We usually have a few men—five or six in a class—whom we know are thoroughly fine men, capable of developing into bright minded engineers; but the others are not of this class. Mr. Raymond has had part of his trouble from the fact that the men whom he gets are average men or men below the average. If he could get

only first quality men, that would be another matter; but we are not all first quality men ourselves. I think we must take cognizance of the fact that the educators of this country have to deal with rather a difficult problem, and therefore we must judge of the college courses, as they are now administered, by the results which they produce. The best engineers that we have in the country at the present day are the product of these colleges. The educators in engineering schools of this country, I believe, are striving to give the young engineer the training he most needs. It would be foolish for them to attempt to educate men in a way that would not meet the requirements of the engineering profession at large. If men were educated just as Dr. Perrine has specified, they would go to the various manufacturing companies, lighting plants, railway plants and no one would have anything to do with them; why? Because they would be so highly theoretical in their view of engineering as a broad problem, that the people would not know how to adapt them to their purposes.

DR. PERRINE:—I never had a student that didn't get a good job.

PROF. GOLDSBOROUGH:—Perhaps the student had a good man to help him get a good job.

It is only fair in view of the fact that the college professor has been made a target this morning, that the college professors should say something for themselves. I won't say very much about college professors; I simply ask you gentlemen to look over the names of the men who have been presidents of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. Look through the country and find the men who have done the work in the INSTITUTE, compare the proportion of work that the professors have done which is recognized as being good, with the proportion of work that the profession at large has done, and draw your own conclusions. It is not always necessary to defend the college professor. Now, suppose all of us had gone through a thorough business engineering training and had become the men whom Dr. Perrine says we ought to be, before we took up our educational work. I will guarantee you, gentlemen, if we had done that thing we would have never taken up educational work; we would have become fascinated and absorbed by engineering problems of various kinds, and we could not be dragged into it. You cannot take Mr. Arnold and make a college professor of him; he wouldn't have it.

MR. ARNOLD:—He wanted to be a professor once.

PROF. GOLDSBOROUGH:—Wanted to be; but found there was too much that was attractive in engineering work at large. Now, the college professor takes this calling up and makes himself a man who is capable, who understands the student; he gets some appreciation of what that student can grasp, and then goes to work and moulds him up. I think the majority of engineering professors go out into the field. I know I take the greatest

pleasure myself in visiting every conceivable factory or plant of whatever kind it may be, talking with men, trying to find out what they know, trying to get in sympathy with the engineering profession at large, and using the information thus gained as best I may in the talks to my students to inspire them with the fact that to be an engineer is a great thing and that they should go into it with all their hearts and might; but when you are telling these things to a turnip, it does not create any sensation at all. In the President's address, there are one or two points mentioned which I will speak of, as I think they should not be passed over, and I hope I will be understood. I appreciate as being very valuable to us, a great deal that the President has said; anything I do not controvert will be taken, then, as having been accepted by me.

As to the competition between colleges: Now, that has been brought up as a bad thing. Eliminate competition between industrial enterprises in this country, what will you have? You will have stagnation. It takes competition between colleges to throw us into the spirit of the thing, to make us think the thing out, to develop good motives, to put them into execution, and make good engineers. If the colleges should stop; if I do not try to find out what is doing, improve my work, make it fit into our advancing education, I cannot give you the men you need; it will be impossible. We must have legitimate, proper competition between colleges as between everything else; it is absolutely essential to the growth and development of our colleges. The President makes frequent reference to the fact that we should teach young men only the bare fundamentals, and mentions in his paper the bare fundamentals in mathematics as well as in all other departments of knowledge. I agree with you that the obtaining of the fundamental idea is the key to the situation; but suppose we stop for a moment and think of some subject that we have studied; if we have ever gone through very conscientiously a long series of investigations, we now retain but a small part of the whole. If we take a man through that very eloquent book that Mr. Steinmetz has written, when he gets through with it, he will have absorbed only a small portion of it, but he gets something and that he will retain. We have to take the boys beyond the fundamentals in order that they may get the fundamentals; we take them beyond in order that they shall absorb the fundamental things they need to know.

I do not think it is necessary for me to say I believe men should have a pretty general culture before they take up engineering. It is absolutely essential. If they are going to be broad-minded, fair-minded men, whom we want to have here, they must have something more than a sordid engineering education. Mr. Raymond would be driven out of his experimental room if he had nothing but the men he has specified about him; it would drive him crazy; he would not stand it.

Now, as regards another point Mr. Steinmetz has made, about

memorizing. I think the great engineer or the great man is a man who can load himself, who for a short time can remember a great deal and can bring it out and use it to the very highest efficiency, and then throw it off and relieve his mind of it. We want to teach our boys how to meet an emergency; we want to make them able at a certain definite time to fill themselves, to enthuse themselves with a subject and come up and meet that emergency, and having met it, be able later to turn themselves to something else. This is not mere memorizing. I do not believe in anything that could be likened to a poll-parrot method of expressing one's self. Boys must understand the underlying theory; they must study the subject thoroughly if they are going to be successful. I think the finest thing in the world is the use of a text-book which has a great many typographical errors in it. Why? For this reason: That when the student has used the book and has worked with it and struggled over the mistakes and finally righted them, he has gained this one great idea, that just because a thing is in print, just because a man of authority tells him it is right, he should not believe it; he should go right to the bottom of the thing and find out for himself. Any instructor who appreciates the work he has to do, appreciates the fact that he must not have the student simply feel that because a formula is in a book, he should use it; there is liable to be a mistake in it, and he should go to the very root of the thing. If a boy goes to a college and never has to take an examination, when he goes out into life he does not know how to meet an emergency. We must throw boys into positions which develop the ability to stand firm in times of stress and not flinch; we must develop this trait in them, or they won't be men —and the sooner we can develop it the better.

I am very strongly a believer in the value of design in the training of electrical engineers. I may be wrong; a number of gentlemen whose opinions I must respect, have said that they do not believe in teaching design; but I am of the opinion that if you let a man operate a steam engine all his life, and do not teach him steam engine design, he never gets the true feeling that he is in touch with the engine. In order to understand what the distribution of the flux in the air gap means, and the effect it has on design, a student has to get right down and figure the thing out, and see the effect of saturation; he has to get so that he appreciates it; he must almost feel that he is inside of the air gap; and then he begins to understand it. I do not mean that the boys ought to study designing because they are all going to be designers; that is not the point at all; but if they know designing thoroughly, they will understand their machinery better; they will be able to overcome difficulties in operating plants better. It is no longer an impossible thing for a dynamo to be designed in a college which will operate successfully after it is built. I presume ten or fifteen years ago that may have been true; it cannot be true any longer. We have far more informa-

tion at our command than the engineers in the factories think we have. I go to one prominent works and the engineers tell me how lamentably the engineers of another establishment have failed; I go to the other place and they tell me the reverse proposition. If the manufacturer does not feel that any other manufacturer in this country can build a good dynamo, I do not feel bad if they think I can't build a good dynamo.

I think that Dr. Sheldon's paper is very excellent indeed and I enjoyed Prof. Esty's paper; I enjoyed Mr. Buck's paper; but I cannot agree with Mr. Raymond in the position he has taken with reference to the instruction which should be given our young men. It would not do at all.

PROF. C. A. ADAMS, JR.:—I cannot tell how much I have enjoyed these papers on the Education of the Electrical Engineer, and the subsequent discussion. We who are teachers cannot help profiting by the good advice given on this subject by practising engineers, by those who purchase our product, so to speak. But while welcoming that advice most heartily, I cannot accept it at all points.

Mr. Raymond has advised us to omit all general or broadening studies from our curriculum; to confine the student to the strictly technical, and says that the time for literature and the like is after a man has become thoroughly established in his profession. If this were true it would be immensely convenient, since one of our greatest problems is to get enough of the technical into a four years' course without slighting the more general training. But my feeling about these general studies is much like that of the Catholic priest about his religion when he said, "Give me a boy before he is twelve years old and you may have him thereafter." The love of literature or the habit of easy and accurate expression of one's ideas, are not easily grafted on, after maturity, but should be bred in the bone and the earlier this training begins the better. As to the need of such training we have to-day had ample evidence from some of our ablest practising engineers who advise relegating most of the strictly technical to a graduate professional course, and in this I agree most heartily, although there will probably always be a demand for a four years' undergraduate course.

Engineering is just as much a profession as law or medicine. Who, more than the engineer, needs a broad training, needs to be able to express himself clearly, so that the public or the capitalist will have confidence in him and his plans? Why is it that the control of so many of our largest engineering undertakings, public and otherwise, are under the control of lawyers and business men? We first of all want a man, and then an engineer.

Of course, there are all kinds of engineers and there will continue to be all kinds of training offered for engineers, and some men will be good engineers no matter what their external training; but I have been speaking of the ideal engineer, of which we see a few among us. We want now to offer every opportunity

for the increase of that number; possibly many members of the INSTITUTE do not know how much the graduate idea has already taken hold in engineering education. For several years nearly 50 per cent. of the students in my fourth year courses were college graduates and some held high degrees. Moreover, these men were almost invariably the best men in the class, not only because of their maturity, but because they had chosen this field of work advisedly and not by accident, as is the case so often. This unwise, unconsidered choice is one of the greatest burdens which the undergraduate technical school has to carry.

President Steinmetz has emphasized the importance of training in the fundamental principles rather than the memorizing of a few of the applications of these principles. With this I am in most hearty sympathy. I am a strong believer in a thoroughly scientific training for the engineer. In fact, I emphasize "fundamental principles" so much in my classes that that phrase has almost become a nickname. But the principles can only be grasped through their application, the abstract through the concrete, and the more practical the application the more useful it is in fixing the principle in the average mind. I even go so far as to include under this head the design of electrical machinery as one of the most effective methods of fixing the principles of electricity and magnetism, bringing in as it does a most thorough problem in the magnetic circuit. It is not intended to turn out fully equipped designing engineers, but rather to teach the student the "reason why" in dynamo design, and to cultivate in him the habit of looking for the reason, of applying his principles.

There is one point in connection with laboratory instruction upon which I feel strongly. Every instructor with large classes to handle in the laboratory, finds it necessary to systematize the work, and the tendency is to sacrifice quality to quantity to put the student through a rigid machine with almost no encouragement to think for himself. The idea of completing a certain set task at a certain time predominates over the desire to understand the experiment for the sake of the understanding. I know it is very difficult to avoid this tendency, but it should be avoided at all hazards; it is the greatest weakness of some of our strongest schools.

DR. C. P. MATTHEWS:—I want to add just one word. The professors have come in for a pretty good share of criticism this morning, but I really think that oftentimes the trouble begins in the home. Many boys go to college and take an electrical engineering course, who are absolutely unfitted mentally for that work. Probably the father has said to the mother, "I am sure that John is fitted for an electrical engineer; why, he got my old medical battery out of the garret the other day, and if you believe, he shocked his grandmother." Now, I submit that it is not obvious from this that John is fitted for an electrical engineer; he may be cut out for a specialist in nervous diseases. That is the only thought I want to bring out; that parents must study the boys.

I think boys should not, as suggested in one of these papers, begin to specialize at the beginning of the high school course; it is better to wait until the end of the high school course. Let the high school course be purely cultural. Do not encourage a boy, it seems to me, to follow any particular line at that early age; you may not at that time have been able to decide, from such an incident as that I have cited, as to whether he ought to be a doctor or an electrician, but at the close of the high school course, he will be 17 or 18 years old, and will show tendencies in one direction or another, and a wise parent, having noticed those tendencies, will send the boy where he can develop them. An unwise parent, on the other hand, will pay no attention to the matter. This latter must be so, because we have many boys in the colleges who have evidently been sent there to get rid of them.

PROF. SEVER:—The methods which some men take to enter college are, as just outlined by Dr. Matthews, very interesting. One of my men goes to Schenectady to work for Mr. Raymond. He entered Columbia University in this manner. A friend of his, a graduate in the same class with him from the College of the City of New York, went to his house the night before the entrance examinations at Columbia, and he said to him, "I am going up to Columbia to-morrow to take the entrance examination; I think I will be an electrical engineer; don't you want to go along and be an electrical engineer?" He went; he took the examinations, passed them successfully, and this year he got the degree of electrical engineer, and I expect to see him become one of the prominent engineers of the future, under Mr. Raymond's instruction.

The matter of broad instruction has been considered very deeply by the trustees of Columbia University, and they have placed themselves on record in the following manner—I quote from a report of a committee appointed by the trustees of Columbia, who investigated this subject very carefully: It states that the trustees of Columbia University have announced it to be expedient and desirable that all the professional schools should be placed on a graduate basis, and this policy, having been adopted as to the law school, is to go into effect in 1903. They place themselves on that broad ground to give a wide and liberal education, and it is being very deeply considered by all the different professional school of Columbia University as to the best method of securing this six or seven years' course for the broader education of the student. It is a thing that cannot come rapidly, because it strikes, as you might say, the vested interests; it must come slowly; but undoubtedly it will come. In our circular of general information, attention is called to this broader and more liberal method of education, in this manner: "The combined six years' course is strongly urged and recommended, for the reason that engineers, chemists, architects and professional men need the liberal training offered by a collegiate course quite as much as do lawyers, physicians or clergymen. Experience has

shown that those who have taken a liberal course of study and have enjoyed the advantages of such an education before beginning their technical studies, have taken a much higher standing in their profession, have exercised greater influence in the community and have been much more useful men than those who have relied upon a purely scientific or professional course of study."

Statistics are given as to the men who have taken this longer course during the time that the opportunity has been presented by our University, and as a conclusion, this is stated: "Further, there seems to be but little demand for a professional training of this kind, based upon a liberal education." Apparently, the demand must be created. The only way to do that is to slowly abandon the 'four years' course of concentrated attention to technical information, and put it upon a six years' course of study. I state this, as I desire to define the attitude of Columbia University in the matter of broad and liberal-minded education.

The matter of examinations is one that touches our innermost soul, especially when we have a hundred men in a class, who do not know very much about the subject and whose examination papers we have to delve over night and day for twenty-four hours a day. We believe in examinations. An engineer, when he has to make a report on a proposition, has to work night and day to do that if he is given a limited time. Note Mr. Arnold's method of work, while he was under examination by the New York Central Railroad, and to the surprise of Mr. Pearson got his report in in less than four months. We do the same with our men; we bring them up to a fighting point, make them tell what they know. I urge the men to cram for examinations; I tell them that is what an engineer has to do and I believe in it. A little different method I think I can cite, if President Steinmetz will pardon me. Columbia University had the honor of having Mr. Steinmetz deliver a course of lectures during this last term to our senior students, in electrical engineering on alternating current machinery. As an examination in that course he sent to each man the data and a set of curves for the calculation of an induction motor. Each man was supposed to work out the results independently, at home, in the drawing-room, or anywhere else. I believe they all did it—at least they all have their degrees—but how they did it I don't know; judging from my own experience in laboratory reports, they may have had instruction from other quarters than that which they secured in the class room—my apologies to Mr. Steinmetz if I am wrong. I do not believe in that method entirely.

I am thoroughly in sympathy with Prof. Goldsborough as to the use of designs in bringing out the application of the principles which it has been our endeavor for three years to instill into the men. We do not expect those machines to be built. I had one machine designed that had 110 per cent. efficiency, but the design indicates to the man what the thing is, where the mag-

netic flux is or is likely to be, where the wire is to be placed; he places it himself; he does it himself, although he does not build the machine. We have been through the Stanley works, we went through them yesterday; I doubt very much whether there are 5 per cent. of the members who visited those works who could tell 10 per cent. of what they saw; and it is our purpose in the engineering schools to show the men where the things are placed and how they are placed, and we use the method of design to teach them that.

As to laboratory equipment, Prof. Owens is an old Columbia man, graduating under Prof. Crocker, and he has had unlimited money with which to install a laboratory. That is quite in contrast with the laboratory in which he pursued his instructions. Mr. Buck also suffered under the same conditions that Prof. Owens did, so far as lack of laboratory equipment was concerned at Columbia University.

We had one Fort Wayne alternator which was belted to the same engine that a Bradley dynamo and a Thomson-Houston arc light machine were belted, and when we added load to the apparatus, we unfortunately changed the frequency of the alternator, and all such things as that; a most imperfect equipment, but you see the result. The arrangement of laboratory apparatus is one that has an unlimited field; we have the perfect arrangement of Prof. Owens and we have the many imperfect arrangements of other universities. I follow absolutely Mr. Raymond's testing department. There is the machine; there is the current; the instruments are in the case; go and get them and connect them up and do the work which is appointed for that afternoon or for that day; get the results. It takes longer, but we do not try to cover as much ground, and what the men do get, we feel they get very well. As to theses, we make a particular point on that, having at least two men work together on a thesis, taking up some engineering subject or taking up some research work. For instance, this year we investigated the inductances of the armatures of the Manhattan generators. Such things as that we feel show the result of our labors on our men during the four years that we have them.

In closing, I can only commend Prof. Goldsborough's attitude regarding his men, his desire to turn out men who are able to tackle every problem. I think that should be the aim of the university; we do not want to take men who are particularly fitted for one factory or another, for one telephone company or another, but we want to turn out a man who has the fundamental principles and who can apply them, no matter where he goes.

PRESIDENT STEINMETZ:—We would be pleased to hear from Mr. Pearson.

MR. F. S. PEARSON:—I have been greatly interested in the discussion this morning. Years ago I was an instructor in technical subjects, and I look back with great pleasure to my experience as a teacher, and even wish that I was back in the

class-room. I am thoroughly in accord with the President's paper, as well as with the views expressed by Dr. Perrine, but there are some points which I would like to comment upon from the point of view of the construction engineer. This morning we have had the views of the manufacturer and college professor. I believe in thorough culture for the engineer; still, I appreciate that the technical schools must take the men as they come, and for the time being must make the best of the conditions. I believe one great function of the technical school should be to raise the standard of education; to do away with the student's idea that the chief end of life is to get a good position and salary at the earliest possible time. Years ago it was cutomary for a lawyer or a doctor to study a year or two only before obtaining his degree, and then commence at once the practice of his profession. The leading colleges have discouraged this plan, until to,day there is hardly a case of a practising physician or a lawyer of any standing, who did not complete a four years' academic course before entering upon his professional studies. I think that is the point at which the technical schools for the engineer should aim. They should impress upon the young man who is about entering on an engineering course that the first thing necessary is to obtain a broad general education. If he does this, his salary and all the advantages derived from a technical education will follow naturally as a matter of course. The idea of commercialism which is so prevalent in the engineering schools, I think is all wrong and unnecessary, because while there are no doubt a great many boys who think they cannot afford a seven years' course or even a six years' course, still the poor boy who wishes to study for the ministry, medicine or law, for either of which he requires six or seven years, finds the means of doing so. I learned the other day that one of our largest technical schools is so overrun with applications for admittance that it seemed necessary to find some means of discouraging or keeping men away. They have adopted the plan which seems to me entirely wrong in principle, of materially raising the price of tuition, in order to discourage men from coming. The right principle for the technical schools to adopt is to raise the standard of admission and thus secure a higher class of students; and then when a man is admitted, raise the standard of work in the school and gradually weed out the poorer students, leaving for graduation a class of very able men. I think in a very few years all men who aspire to become electrical engineers will see the necessity of the seven-year course. I believe the engineers should have a thorough knowledge of Latin and a fair knowledge of Greek; not that he will ever need them in his engineering work, but for the mental training and culture that a man gets from the study of these languages, and the great aid they are to him in the study of modern languages. The time required for these studies in my opinion is well spent. I do not agree with some of the speakers here on the question of French and German; I believe that

French and German are essential requirements of every engineer's education. Some of the ablest men to-day in mathematics, chemistry and physics, are writing in French and German. The French and Germans themselves, the Russians and Hungarians, in fact all of the European scientists are publishing their works in French or German, and the American engineer, to be thoroughly posted in the progress of his profession, must be able to read foreign languages. Furthermore, if a man takes up consulting engineering and construction work as a profession, he will very likely be called to foreign countries in a professional capacity. In my experience I have been employed in professional work in Germany, France and in Portuguese and Spanish-speaking countries. I do not pretend to be master of all these languages, but a knowledge of French and German makes it much easier to acquire a slight knowledge of Portuguese, Spanish or Italian, or in fact, any other language, especially if one has studied Latin and Greek; and a man who has a knowledge of French and German so as to speak it slightly and read it easily, is much better equipped for consulting engineering than the one who has no knowledge of them. For this reason I should advocate the study of French and German in the colleges to a sufficient extent to enable one to read them without difficulty, that is, be able to pick up any scientific book or periodical in French or German and read readily without a dictionary.

As regards the teaching of machine design in college, I am a believer in it to a certain extent. I do not think a student can be taught to design a piece of electrical apparatus that will be a commercial success. He must learn that by association with men who have had experience, and long experience, in designing; but there are very few men who have the faculty of applying to practical purposes theoretical knowledge; and even if a man has been taught the higher mathematics and its application to electricity, unless some chance is given him to apply this knowledge in the designing of apparatus in the class-room under the direction of the professor, who can point out to him wherein he is deficient and to whom he can go when he does not understand thoroughly the application of the theory, he will leave college without thoroughly understanding the subject, and it is very difficult for him to acquire this knowledge after he has entered practical work. For that reason I think designing is a very valuable adjunct in a scientific course.

There is one point that has not been touched upon at all this morning, except as the President has referred to it, and I do not quite agree with him in this matter. I think the electrical engineer should have a very thorough grounding in civil and mechanical engineering, as well as in mathematics, physics and chemistry. Electrical engineering is to my mind, without any disparagement of the other branches of engineering, at the apex of the science. The electrical engineer has to do with the development and utilization of energy, and to accomplish this, a knowl-

edge of civil and mechanical engineering must be applied in the construction of the work, and later in its operation. An electrical engineer to be successful should have a thorough knowledge of civil and mechanical engineering, and I feel that the ideal electrical engineering course should extend over seven years; the first two years to be devoted entirely to academic subjects, such as mathematics, Latin, French, German, history, political economy, logic, English literature and the various other subjects a man ordinarily takes in an academic course. The second two years should be devoted to general engineering subjects and mathematics, chemistry and physics, but not necessarily to electrical engineering subjects, among which should be included civil and mechanical engineering branches, such as applied mechanics, graphical statics, designing of framed structures, strength of materials, construction of masonry and foundations, character and value of various materials used in construction, hydraulics, gauging streams, construction of dams and canals, and methods of utilizing water in the development of water powers, steam engineering, thermodynamics, etc. An electrical engineer should understand all of these subjects before commencing his special work to which the last three years should be devoted.

With such a course as outlined, the graduate will be in a position to understand any character of work that may be offered and his promotion should be rapid. In this way we shall have a broadly educated engineer, and one that will be an honor to his profession as well as a good member of society.

PRESIDENT STEINMETZ:—Before proceeding further with the discussion, I should like to give the floor to the Committee on Resolutions, Messrs. J. W. Lieb, Jr., C. O. Mailloux and F. A. Pattison, for the presentation of their report.

Secretary Pope read the report of the Committee as follows:

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, desiring to acknowledge the many courtesies extended to it on the occasion of the 19th Annual Convention of this INSTITUTE, held at Great Barrington, Mass., June 17th to 21st, and to record its gratitude for the splendid hospitality enjoyed by its members and guests, begs to transmit to you this official expression of its sincere thanks.

At the closing of the Convention, held June 21st, the following resolutions were unanimously adopted:

Resolved, that the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, being deeply sensible of the many favors and courtesies received by its members and guests during this Convention, hereby tenders its sincere thanks to:

Mr. and Mrs. William Stanley.

The members of the Local Executive Committee.

The committee and members of the Thursday Morning Club.

Mr. E. F. Searles of Barrington House.

The Wyantenuck Golf Club.

The Stanley Instrument Company of Great Barrington, Mass.

Dr. and Mrs. F. A. C. Perrine.

The Mayor and Board of Aldermen and Local Committee of the City of Pittsfield, Mass.

The Country Club of Pittsfield.

The Pittsfield Street Railway Company.

The Stanley Electric Manufacturing Company.

The American Telephone and Telegraph Company.

The New England Telephone and Telegraph Company.

The management of "The Aspinwall," Lenox, Mass.

Resolved, that the thanks of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS be transmitted officially to each one of its hosts above named.

Signed and Sealed. THE PRESIDENT AND OFFICERS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

MR. RICE:—Mr. President, as chairman of the Committee on Papers and Meetings, I beg to move the adoption of the resolutions that have been offered; and in making this motion I want to, if it were possible, express to our hosts the appreciation that we feel. I am hardly able to do it; it is more than one can express in a few words. We have been delightfully entertained in your homes.

MR. MAILLOUX:—I am very glad indeed to have the motion made by Mr. Rice, as Chairman of the Committee on Papers and Meetings. I am also glad as a member of that committee to join hands with him and help sustain the motion by seconding it.

MR. LIEB:—A communication from the Albany Institute of Arts in reference to the Joseph Henry memorial, requesting that the matter be brought before the INSTITUTE at this Convention, was referred to the Committee on Resolutions. The communication was accompanied by an announcement, which the Committee lays before the meeting with the recommendation that the matter be referred to the Board of Directors for further action.

PRESIDENT STEINMETZ:—This communication has been laid before the INSTITUTE for proper action, and it seems to be proper to refer it to the Board of Directors, and I therefore do so.

After having had the great pleasure of passing the resolutions reported by the committee, I am only sorry that we cannot attempt adequately to present our feelings of gratitude to the generous people of Great Barrington and Pittsfield.

PRESIDENT STEINMETZ:—It is my very great privilege as President, and I take extreme pleasure in being able here for the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, to present to the President and Executive Committee of the Thursday Morning Club, a very small token of our appreciation of the splendid work they have done and the great results they have achieved in entertaining the INSTITUTE so royally and thereby making a mark in the history of the INSTITUTE by securing results which

have never been achieved before, and I am afraid will not be achieved again for a long time to come. I take great pleasure in presenting you this loving cup.

MRS. LANE:—Mr. President and Members of the INSTITUTE: On behalf of the Thursday Morning Club I thank you. This week has been much more to us than perhaps you realize. It has proven to us the strength of our organization, and shown to us that that very strength comes from union. We will keep this beautiful reminder of your visit as a symbol of that union. Again I thank you. (Applause.)

[Adopted by a rising vote.]

The discussion upon the educational papers was then resumed as follows:

MR. MAILLOUX:—My views on the subject of education in general and of engineering education in particular, are somewhat radical, and I therefore expect to astonish and shock some of the members present. I concur heartily with the remarks of Dr. Perrine, who is especially well qualified to speak on this subject by reason of the opportunities which he has had to study it, as a teacher of engineering, as a practising engineer, and also as an employer of engineers in relatively large numbers. I also wish to commend especially the papers of Prof. Esty, of Mr. Buck and of President Steinmetz, which seem to me to contain excellent ideas and to outline the entire subject very intelligently. The papers and the discussion have shown that there are many points on which we all agree, and that our differences sometimes exist more in the definition than in the substance of our ideas.

Victor Hugo, in the first page of one of his great novels (" The Man Who Laughs ") speaks of a certain physician who " sometimes cured, *because of* or *in spite of* his art." I believe that this cynical comment on the art of healing would be a good text for a discourse on the " art " of engineering education, for it is with engineers as with doctors; they " engineer " *because of* or *in spite of* their engineering education. We all know of engineers who have succeeded *because of* their training, as we also know of those who have succeeded *in spite of* it. The text furnishes convenient names for two distinct classes of engineers, from the educational viewpoint: the " because-of " class and the " in-spite-of " class. The constituency of each class will depend upon the definition of the terms " engineering education " or " technical education." The strict academic definitions would reserve the "because-of" class for technical graduates only, or at least for those only who have had adequate special technical training in scientific schools. The objection to these strict definitions is that they would relegate to the " in-spite-of " class too many worthy names, including stars of the first magnitude, such as Faraday, Edison, etc.; and, consequently, the definitions must be extended so as to make education independent of *place*, or *time*, or *method*, of teaching, and so as to accept or admit knowledge as knowledge, just as gold is accepted—for its intrinsic worth—irrespective of *how*,

when or *where* it has been acquired. I believe it to be somewhat unfortunate for the best interests of engineering education that so many, both among pupils and teachers, " judge the goods by the label on the wrapper." The teacher too often fails to realize and to appreciate, or, at any rate, he too often fails to impress upon the pupil, the important distinction between what one has *studied* and what one has *learned*, or what one *knows*. I will illustrate this point by an incident. Some time ago I had a discussion with one of the technical assistants in my office over certain technical questions which were involved in an engineering problem under consideration. The assistant, who evidently considered his knowledge of a " brand " superior to mine, informed me, after his arguments had been completely refuted, that he " ought to know," because he had studied fourteen semesters in German scientific schools." I informed him that " doubtless he *ought*," if he had studied even a shorter time, but that "assuredly he *did not*" know; that what was really interesting and relevant in this case was, not how long he had *studied*, but how much he had *learned*; not what he had *forgotten*, but what he *still knew*. I then insisted upon having the question in controversy referred to a competent third party, as referee, satisfactory to both of us; and his decision, rendered without knowing either party, was a triumph for the cause of knowledge " which is " and a defeat for knowledge " which has been." This is not by any means an isolated case. I could mention numerous other similar incidents to show that " there are others," and they do not, by any means, all come from German schools—who count as part of what they know, much that they have never known, simply because they once studied it, or studied " at " it.

Prof. Esty speaks of the " common complaint among practical electrical engineers that college graduates are not practical." Mr. Buck argues that the training of the engineer should combine both theory and practice. My own view is that engineers are not practical enough simply because they are not theoretical enough. I believe that if the college graduate knew more of the fundamental theory, he would understand the fundamentals of practice better, and would make more rapid and satisfactory progress than he usually does, in acquiring familiarity with practice. Hence, in that respect, although the college professor might expect me to differ from him, I really agree with him. I strongly believe in theoretical knowledge, but I think it ought to be *thorough* rather than *extensive*, if it cannot be both. I believe strongly that it would be better to teach only the groundwork, the elementals, so to speak, of both theory and practice, and to do it thoroughly, than to attempt to rear a showy superstructure upon a flimsy foundation.

I do not take kindly to the recommendation of Mr. Raymond that the vocation of a boy should be selected and fixed for him by his parents or teachers, while he is still in the high school; and I differ radically with his view in regard to encouraging students

to specialize early. I have had a little personal experience with that plan, and I must say I do not like it. I am, myself, an unfortunate example of the boys whose career was selected for them while still in the high school. My parents then elected to fit me for the profession of medicine, and I was schooled largely with that object in view; so I began to "specialize" early. I spent, in the study of medicine, three or four valuable years, and I have often wished, since, that I had devoted the same time to general scientific studies, instead of specific scientific studies. The time was not all lost, for the reason so well stated and illustrated by Prof. Brooks, that *all* knowledge is useful; and the knowledge then acquired by me has been of utility more than once, even in my present vocation. These studies, considered as factors of mental training and development, were of undoubted benefit and value, though not as much so as certain other less specialized studies would have been.

Mr. Raymond's analogy between the violin student and the engineering student, which is presented as an argument in favor of early specializing, is both physiologically and psychologically wrong. The violinist needs *manual* dexterity, involving the power of control and coordination of certain muscles of the arm and hand—the training of portions of the human organism which can attain their full development at a very early age. The engineer needs *intellectual* dexterity, involving the proper education and coordination of his perceptive and reasoning faculties—the training of the brain, the portion of the human organism which is the very last to attain its full development.

Mr. Stanley's allusion to the importance of broadening one's horizon, and his reference to the "pyramid of knowledge," are happy thoughts, full of meaning, which, I think, should be well borne in mind. The further definition of that "pyramid" might be made by reference to Prof. Agassiz's definition of a learned man as "one who knows everything about some thing and something about everything."

The apex of the pyramid represents the "everything about some thing"—or the particular specialized knowledge of the individual in his "specialty"; and the base represents the foundation of general education, mental training and intellectual development or culture, which are necessary to encompass, support and hold together the mass of the pyramid, containing and constituting the "some thing about everything." The higher the point at which the apex of the pyramid is to be placed, the broader and the more substantial must be the base, and, what is very important, the greater the time which must be allowed in building it. In a word, the process of building a large, solid, finished "pyramid of knowledge," in the human brain, is incompatible with early specializing or insufficient preliminary training and general education. I believe strongly in general education. I believe that education of any kind is a broadening and lifting force which develops the individual and helps him to rise to a

higher plane in engineering, as in all other professions. I heartily approve the new plan of Columbia University to lengthen the course to six years, with the first three or four years devoted to general education. It would be better still if the entire six years could be devoted to general training. I have such respect and appreciation for general education, that, were I able to begin all over, I feel that I would devote twelve years instead of six to the preparation for a technical curriculum.

After an experience of nearly twenty years in teaching myself and also in teaching others occasionally, I have come to the conclusion that so far as the *ultimate* result is concerned, it does not make so much difference by what particular course of study the preliminary training of the pupil is accomplished, provided it be broad and thorough.

The objects sought are, briefly stated, to foster taste and develop capacity for study, to make the perceptive faculties more active and keen, to develop the powers of observation, thought, analysis and synthesis, to enlarge the scope of the reasoning faculties, and, in general, to broaden the intellectual horizon. Any process, method or means of training which attains these objects must be accounted good, for it equips the mind with the three graces—aptitude, application and judgment—which are the handmaids of success, that point out and prepare the easiest paths to distinction, making the process of acquiring skill and experience less tedious in *any* vocation. Such a man is placed at a disadvantage only temporarily by the want of " practical " or specific technical training. When he does catch up with his colleagues who have less general but more specific training than he, they are likely to be left behind. It is a matter of universal observation that the individual who has the most broadly and highly trained mind acquires practical experience and skill the most rapidly. The usual comment is that he is " brighter " and " smarter " than the rest. What is really meant is, that he naturally has, or else has acquired by training, more aptitude, more application and better judgment (and the other qualities which accompany them) than the rest.

In regard to practical experience, it is admitted by all that the school is not, to say the least, the best place to acquire it. The most that the school can hope to do is to prepare the student so that he can acquire experience easily and quickly; and, as I have already indicated, I believe that general scientific training is as good preparation as any for this purpose. I concur, to a great extent, with the opinion of Dr. Perrine that students should not be taught too much practical work. While I do not wish to be understood as disparaging practical training in schools, yet I strongly believe that, seeing the impossibility of giving a thoroughly practical training in schools, it is better to waste no time on practical training that could be advantageously and profitably used in perfecting, in broadening and deepening the theoretical training.

One of the great qualities needed in any engineer is *receptivity*. If the young man were drilled thoroughly in fundamental principles instead of being given a smattering of them, together with a smattering of practice, he would not be deluded, as he so often is, with the idea that he has already learned all that is worth knowing, both theoretically and practically, and that knowledge and experience have no new fields for him to conquer. One of the hardest things to eradicate from the mind of the young engineer is oftentimes that very feeling, which, in many cases, amounts to a conviction, to the effect that his technical curriculum and his professors have already given him a panoramic survey of all that is worth seeing, noting and knowing, in the domain of theoretical and practical knowledge. To do justice to the young engineer, let us admit that this feeling represents a phase of human nature which is not characteristic of his age or of his school, since it exists quite generally. It is that same phase of human nature which animates many tourists, who come and go so quickly that they stop only long enough to carry off the dangerous delusion of having seen and learned all, when, as a matter of fact, they have scarcely seen or learned anything. I am, therefore, inclined to think that a smattering of practice is worse than none, and that perhaps a thorough science training would be as good for immediate results, if not better, and that it would be certainly superior for ultimate results. Examples are not wanting of men who have become eminent, both in theoretical and practical lines, whose preliminary training was greatly, if not wholly theoretical. The success that has been achieved by those who have had neither theoretical nor practical training, in technical lines, but who have had merely general intellectual training and discipline, is an indication of the great importance and benefits of a training in which the individual is taught *to think* and *to study*, that is to say, whose mind has been developed to the highest possible degree of *receptivity* and *assimilative* power. I could point to many examples of successful engineers, whose preliminary education and training have been on general lines, perhaps only classical or literary. These men generally understand and recognize, or, at least, they admit their limitations more readily than is apt to be the case among those who have received a strictly technical training. My observations have shown that a little knowledge, especially in practical matters, is very dangerous, because it too often inspires a dangerous confidence in its possessor. Without this knowledge, the student might have had the courage to say, " I don't know." With it, he tries to think, and to make others think, that he " knows," too often to the detriment of his own reputation and of the interests with which he is identified. Dr. Sheldon has surmised quite correctly;—"That which the technical graduate lacks," *is too often* " the broad-mindedness associated with graduates from classical and art courses, and which, as a whole, is considered as an indication of a liberal education."

I now come to an important question which forms a subject of contention, so to speak, in this discussion, namely, the utility of languages. I fully endorse Mr. Buck's opinion about the necessity of a good training in the English language, and about the drawbacks of an undeveloped and uncultivated faculty of oral or written expression. I therefore disagree and most emphatically, with Mr. Raymond, who would drop the study of English, rhetoric, composition, etc., from the curriculum for the training of engineers. The faculties of thought and of expression are so closely related, physiologically, that the dwarfing of one necessarily dwarfs the other. It is my opinion, and I believe observation confirms it, that the individual who neglects to learn the important art of clear expression has handicapped his intellectual faculties to a great extent, for he has not attained his full possibilities in the direction of clearness of thought. I also differ radically with Mr. Raymond on the question of foreign languages. I will first refer to the so-called dead or classical languages. I was extremely pleased to hear so distinguished an engineer as Mr. Pearson put in one good word for Latin. It happens that Latin is one of my hobbies. I began the study of languages at an early age. When I left high school, I had a fluent knowledge of three modern languages, besides a fair knowledge of Latin and a little knowledge of Greek. To-day, the only magazine which I read regularly is a Latin magazine, *Præco Latinus*, which I recommend to all lovers of scholarly Latinity; and I am proud to say that not only have I retained the knowledge of Latin and Greek which I had when I left school, but I have increased my "stock" of Latin, until I am considered to-day, by my good and indulgent friends, as knowing something about Latinity. I have found Latin useful not only as an intellectual rest and recreation, but as a means of mental training and discipline, as a means of improving diction, and as a means of philological, literary, philosophical and historical instruction. I regard both Latin and Greek as a most valuable mental training and accomplishment. I have the same high opinion of modern languages. I remember reading, shortly after I left school, an allusion to the statement said to have been once made by a noted linguist, Charles V., of Spain, to the effect that "a man is as many times a man as he understands languages." I was wise enough to know that a man cannot multiply himself indefinitely, but having then a knowledge of three modern languages, I could realize by practical results, that there was something in this thought, for even the knowledge of only three languages had extended my intellectual horizon; it had increased my intellectual perspective; it had enabled me to look stereoscopically, so to speak, at many ideas which otherwise I could only look at from one point (through one language), whence it would not be so easy, if it were possible, to see them in their true relative position. I have, therefore, made it a point to continue the acquirement of linguistic and philologic knowledge; I now speak five modern

languages, and can read as many more, and I hope to speak ten and read twenty before I die. Such is the estimate which I place upon a knowledge of languages as a factor of mental training and equipment. I consider it second only to *good* mathematical training, and quite superior to *poor* mathematical training as a means of mental development. It has the advantage over mathematics of having less tendency to develop "abstractedness" of reasoning. I do not consider this as applying necessarily to all persons; I know many persons who cannot acquire languages, in spite of hard effort. I know others who acquire languages very easily. To me, languages have been useful in the same way as the abstract study of mathematics, to the extent that they tend to develop the intellect, increase the mental perspective and broaden the intellectual horizon, and also, besides, to the extent that they are of practical utility for the purposes and in the way very ably pointed out by Mr. Pearson. I stand with him firmly on the ground which he takes, that no engineer who ever expects to fill an important position in the world—especially one who aspires to international reputation—should neglect the study of languages. I consider a knowledge of French and German just as important a part of a man's intellectual equipment as any of the other studies.

If I had any suggestion to make in connection with the teaching of languages, it would be that the study of languages be put at the very beginning of the curriculum, or, indeed, that it should precede the technical curriculum.

We all know that the acquirement of a foreign language, which is relatively easy in youth, becomes more difficult as age advances. The early study of a foreign language, therefore, is desirable, because the task of acquiring the language is thereby simplified. It is also desirable for another and still more important reason, namely, because of the importance of language as a means of mental development and discipline. It cannot be denied that the study of foreign languages, as well as the study of the classics, during youth, has a powerful effect in teaching the mind how to assort, assimilate and assemble ideas, and especially how to differentiate shades of meaning. Now, when a person begins to distinguish between shades of meaning, he must have learned, or he is learning, to differentiate between shades of thought, and that is a step of the highest importance and value in technical training. It is for this reason that the study of foreign languages is regarded by many as an important course in the art of clear thought and clear expression.

I now come to the question of mathematical training, which is in my opinion, one of paramount importance. I agree, substantially, with Mr. Steinmetz in regard to the amount of mathematics which should be included in an engineering course. I am a partisan of mathematical knowledge as an important item of the engineer's professional equipment. I believe strongly in both *quantity* and *quality* of mathematical knowledge; but

when both cannot be conveniently had, I am strongly in favor of sacrificing quantity for quality. In this connection I wish to remove the onus which is wrongfully placed upon the men who actually educate the electrical engineer. The professor of electrical engineering has, so to speak, "caught it" rather hard, and, in my opinion, most undeservedly; he has been held responsible for many failures in turning out competent "engineers," which ought properly to be credited to some of his colleagues in the faculty—notably the professor of mathematics. The truth is that the mathematical preparation of the students is, in a large number of cases, quite incomplete and inadequate. That is why they stumble in the analytical and applied mathematical studies. Dr. Perrine's allusion to the course in differential equations, which he had such difficulty in arranging, is an interesting revelation. As the result of extended observation, and of the confidences of many engineers and students during the last fifteen years, I have come to the conclusion that much of the deficiency in engineering education, both theoretical and practical, is due to the difficulties which are *made* instead of *removed* for technical students, by their teachers in mathematics. I have begun to look upon mathematics, both pure and applied, as taught by many college professors, as a means of befogging the pupil, of obscuring his mind, of literally putting difficulties in his way, instead of enlightening him and facilitating his progress, as should be the case with proper teaching. I have two nephews now following engineering courses. I found that both had difficulty in keeping up with the course in calculus. I undertook to help one of them at his request. I found that he lacked knowledge of the fundamental preliminary principles forming the groundwork of the subject; it was like trying to learn square root before learning multiplication or division. When I inquired whether these things had not been taught him and why they had not been learned, even before entering upon this study, I learned that the young man, in common with the great majority of his class, had been groping and stumbling in the dark during the entire term. Only a few of the students were still pretending to follow the professor, who had been, all this time, to use their own words, "talking to himself and over our heads." The professor had evidently done his best to "keep ahead" of the students, and he had run no danger of being overtaken. The young man naturally had "mathematical indigestion," in rather aggravated form, as the result of trying, for weeks, to gorge his mind by main strength of memory, with undigested mathematical "pottage."

As pointed out in the Presidential address, by Mr. Steinmetz, (who may well be deemed an authority on subjects mathematical) the memory will not retain formulæ which the mind has not *analyzed* and *understood*. I took advantage of a vacation week to give the young man a new start, by going back with him to the very beginning, and laying a solid foundation of *elementary*

fundamental knowledge. The difficulties complained of vanished quickly, and the young man then made satisfactory progress. His natural ability is such as to force upon me the conclusion that his deficiency was entirely due to inadequate teaching.

Quite recently, I had occasion to help another young man, who is a recent graduate of a well-known technical school, to take a fresh start in some of his mathematical studies, including calculus. He also had been a sufferer from the same kind of indigestion, pretty much for the same reason. I could cite at least a dozen similar cases; and in all of them I really blame the teacher more than the pupil. It is a well-known fact that the percentage of graduates who retain sufficient interest in their mathematics to care to keep up their knowledge and increase it, after leaving school, is extremely small. The great majority proceed to " forget it " with a rapidity which almost savors of alacrity; and, in come cases, they become empirical to an extent which makes even a non-graduate " practical " engineer blush. What is the cause? *Mathematical dyspepsia.* The mathematical " indigestion " from which the students suffered for four years, while in college, has become chronic—it has become " dyspepsia," and mathematics are no longer palatable because " they never did agree with him." He literally, and to use his own words, " has had already more than he wants of it." He therefore falls into " practical " ways, and is fortunate if he does not evolute to the point of wondering what mathematics were ever invented for, anyhow.

Having had to teach myself mathematics (beyond the mathematics acquired in a high school course), and being a rather poor pupil, I needed very patient and somewhat scientific teaching. That is why I have given so much attention to the study of methods of teaching. I still am engaged in the study, both as the pupil and his teacher. Mathematics are a part of my " post-graduate work," and I find it interesting and profitable to devote many hours of leisure to them. I have had occasion to help others to get knowledge of the subject, and I have discussed the matter of teaching mathematics with many teachers, among whom I will mention Dr. John Perry of the Royal Technical College, London, whose name stands among the foremost in electrical science and in engineering, and stands in the very front rank as a mathematician and a teacher of mathematics. During the visit of our INSTITUTE to England in 1900, it was my pleasure to meet Dr. Perry on many occasions (he then being President of the Institution of Electrical Engineers), and to study him as a man, as a scholar and as a teacher; and, in common with all the American members of this INSTITUTE who were guests of the Institution of Electrical Engineers, I learned to admire and esteem him greatly. I had occasion to discuss with him the subject of teaching mathematics, both from the standpoint of pupil and teacher (both sides being interesting to me for the reason already stated); and I was very much pleased and en-

couraged by what I considered his very sensible views on the subject. He was the first mathematical teacher that I had met who had enough imagination and judgment to put himself in the pupil's place, and to properly appreciate the pupil's difficulties and note his needs. I found with pleasure that he had been for some time preaching reform in methods of teaching mathematics in England. He had found as the result of extended experience as a teacher, that only few mathematicians are "born"; that the others have to be "made"; that the present methods of "making" them were not fully satisfactory, and might be greatly improved. He gave me a copy of his "Practical Mathematics,"—a summary of six lectures delivered to workingmen," and I would recommend every engineer, and even every teacher, to procure and read these lectures. I read the book on the steamer, and found it so good, that after I arrived, I procured a half-dozen copies, which I sent to various friends who, I knew, would be grateful for light on the subjects discussed by Dr. Perry.

At the last engineering congress, at Glasgow, in 1901, Dr. Perry read a paper on the teaching of mathematics, which I also recommend to every man who has had to struggle to get light on that subject, whether he has been through a university or not. This paper formed the nucleus or the starting point of an interesting discussion, constituting an able symposium, in which the ablest mathematical men in England, from Lord Kelvin down, took part; hence it is not the expression of a few desultory or sporadic thoughts on the subject, but it represents the entire analysis of the question of teaching mathematics. You will find that the conservative teachers, "the Euclidians," do not hit Prof. Perry very hard, notwithstanding the extremely radical views which he took on the subject. I also recommend Dr. Perry's presidential address before the Institution of Electrical Engineers as most profitable and wholesome reading for engineers. It seems to me that many mathematical authors especially in America, write their books, same as some professors lecture, for an "audience" of professors and critics rather than of students. The mathematical professor should use his knowledge to *impart knowledge* to his pupils. He too often uses it to *impress them with it*, merely. In discussing methods of teaching with some of them—not of Dr. Perry's kind but of the old-fashioned kind—I have been surprised to see the importance which they ascribe to the adjectives *terse* and *rigorous*. Many of them apparently think that they lose dignity unless they are strictly "terse and rigorous." Because, figuratively speaking, they themselves can clear almost any obstacles with a stride or a jump, they assume that the poor student ought, can and must do the same. The student, therefore, finds himself, in most cases, just as much handicapped as if he were trying to keep up with a fleet-footed runner, who is also a good, all-around and well-trained athlete. When the steps of the reasoning are too large for the mental

grasp of the pupil, he memorizes them without understanding them, which means that he does not really learn the reasoning but takes it for granted. In such a case, mathematical study does not strengthen and discipline the mind, but does the very reverse. If, on the other hand, the pupil were led over a less steep and precipitous path, even though it were apparently a much longer path, he would not be so likely to lose courage or lack confidence in himself or his teacher, and, as I have found repeatedly, he would attain the goal more often, with less effort, and in less time, than he does by the orthodox " terse and rigorous " route. In this case the student, being able to see the steps without difficulty, can use judgment, instead of trying to rely wholly on memory, in following the road. His reasoning faculties are exercised and trained without straining the memory—which is, in my opinion, the most satisfactory method.

While it is true that there is no royal road to mathematical knowledge, it is certainly a great mistake, in my opinion, to imagine that the best road is along the line of maximum effort. I believe, on the contrary, that the best road lies along the line of least effort. I am not in sympathy with the idea of some teachers that it is necessary to make a thing difficult in order to have it well learned and remembered. We begin the physical training of children by light gymnastic exercises, not by physical efforts which would strain the athlete The same rule should apply, *a fortiori*, in intellectual training, for the important physiological reason already noted, namely, that mental growth is essentially a slow process, which should never be forced. The intellectual gymnastics should be such as involve the least mental *effort*, and produce the most intellectual *exercise*. One orthodox teacher of mathematics argued that the teaching should not go so far in elucidation, as to literally " put the dot on the i " for the student; I agreed; but I insisted that the pupil should nevertheless be taught that there *is* a dot, and where it ought to be put on that i, instead of being allowed to guess it. In this connection I wish to call attention to the striking contrast between French and American mathematical text-books. The French mathematical teacher believes in the " rigorous " just as much as his American colleague, but he has no sympathy for the " terseness " which is secured at the expense of *lucidity* and *intelligibility*. He does not hesitate to devote pages, sometimes, to the elucidation of topics which the American text-book treats " tersely " in a short paragraph. He follows the line of least effort. His book is more bulky, but it is far more easy to " digest " than the American text-book. Instead of being a cause of intellectual dyspepsia, it is, on the contrary, a prophylatic and a cure for it. Instead of destroying the taste and aptitude for mathematical study, it stimulates and develops them. I would advise all science students to study and master the French language, if only for the assistance which it will place at their disposal in their studies in pure and applied mathematics. There are many

American teachers, especially among those who write text-books, who could profit by the same advice. A few of them have already done it, or are doing it, I am glad to say, and it is to be hoped that their study of books, such, for instance, as Briot's admirable text-books of "lessons," (in algebra, trigonometry, analytical geometry, etc.), which have run through fifteen or more editions, may inspire some ideas of reform in methods of teaching. It may be a mere accident or coincidence, but the fact is interesting, that by far the most thoroughly trained and able young graduate engineers in a mathematical sense, whom I have ever had in my employ, were the product of French methods of teaching and of French schools.

In concluding this portion of the discussion, I wish to express the opinion that Dr. John Perry deserves the applause and the gratitude of all who believe in mathematics, for the crusade of reform in methods of teaching which he has inaugurated. His recognized mathematical learning and scholarship, his international reputation as a scientist, his writings, his lectures, and above all, his long personal experience in teaching pure and applied mathematics, make him a most competent and authoritative judge and critic of methods of teaching mathematics. His opinion to the effect that reform is needed, may well be accepted as conclusive evidence that *it is* needed.

Dr. Perry will, I hope, forgive me for betraying his confidence, as I am now about to do, to the extent of disclosing some of the "details" of his method or "art" of teaching, which are quite pertinent to this discussion, and which show, incidentally, that he can teach other things than mathematics and engineering, and with success. Reference is made in some of the papers, especially in Dr. Sheldon's paper, to the importance of developing or disciplining the emotional and æsthetic sides of the student's nature. Dr. Perry also lays great stress on the cultivation of the higher mental attributes, more especially the *imagination*, the development of which he deems of great importance as a factor of the student's progress in his studies and his success in technical work. He informed me that he studies carefully the pyschology of each of his pupils, and when he finds the imagination deficient, he proceeds to apply a "stimulant" in the form of non-technical general reading. He showed me, in his study, at the Royal College, a well-stocked library, which he has gathered together almost for that express purpose. In some cases he may "prescribe" and "administer" poetry, in others, history, general literature, travels, romance and adventure, according to the "case." I was surprised to find Cooper's novels, and most of our standard classical American novels, in his lists of authors. I was also surprised and gratified to note Dr. Perry's wide knowledge of our literature; but I was still more surprised at the scientific manner in which he used it as a stimulant for the imagination, and as a "developer" of the student's broader culture. He related numerous cases, giving the "diagnosis" and the

" treatment " and the gratifying results accomplished. He cited cases where a " cure " or, at least, great improvement was effected by the perusal of a few stirring novels and an occasionally friendly " talk." His pupils all admit that he is a great and successful teacher, who has the rare faculty of retaining the attention and keeping up the interest of the students, and of infusing individuality into them. It is my opinion that Dr. Perry could teach many teachers valuable lessons in the *art of teaching*.

Before concluding, I wish to applaud heartily and to emphasize strongly the pertinent, well-deserved criticism made by Mr. Pearson, to the effect that the present methods of education are apparently too sordid, and aim too much at the *immediate* result, and too little at the *ultimate* results. The schools may not be altogether to blame for this. Prof. Esty distinctly advocates the kind of technical education " which aims not to make the graduate immediately successful in commercial life, but aims rather at ultimate success." Doubtless many of his colleagues hold or would like to hold this broader view, but the public, the parent and the student do not, unfortunately, take this broad view, and they have created a " demand " for the " other kind" of education. In justice, we must admit that it is they, and not the schools or the teachers, who are " sordid." They too often consider engineering to be a " business " instead of a vocation. The student is too often the raw material from which his parents, friends and advisers want the professor to turn out, not an engineer, but a wage-earner. The young man has chosen this or that branch of engineering, not because he really deems himself most apt and fitted for it, but because " there's money in it." In other words, the end in view is *dollars*, as many and as quickly as possible, rather than what it ought to be, namely, *attainments* primarily, and *emoluments* secondarily. This is only a very natural propensity perhaps, in the age and in the land of the " mighty dollar." Like Mr. Pearson, I do not admire this propensity, even though it be growing in " popularity." It demoralizes the scientific spirit, and tends to lower the standard of professional ethics. I am often asked by young men, just out of technical schools, what is the best thing for them to do, or what is the best way for them to " start." I have always made it a point to begin the answer to their questions by asking them questions, such as: " Do you wish to go *quickly* or to go *high*? What is your ultimate object in this ' business? ' Do you merely want to become a hundred-dollars-a-month man or so, or do you wish to attain the pitch, the standing, the value, call it the " earning capacity," if you will, of a thousand-dollars-a-month-man? The young man generally admits that he would rather join the one thousand dollar class; but when I explain to him the laborious process, and point out the long tedious roads which have to be followed in order to become qualified for that class, he very often becomes discouraged, and concludes that he will take the

short cut route, and trust to " luck " or " business ability " to get above the $100 class. The truth is, that in qualifying for the $1,000 a month class, he must spend more years in training " *at both ends of his course* " *i. e.*, both after and before graduation; in other words, he must *broaden*, *deepen* and *strengthen* his education in every way possible. He must not expect immediate results; he must not start with the notion that he is at once so valuable to his employer; but he must spend years and years building the foundation, acquiring practical knowledge, acquiring theoretical knowledge, fortifying and consolidating theory by practice, and solidifying his theoretical knowledge, developing the qualities of individuality, originality and resource, until he is able to grasp difficult, intricate problems, and handle them with little or no difficulty. This means years of application and effort.

There is a valuable suggestion in Mr. Raymond's paper, in the statement that " the college graduates should consider that the knowledge gained at the university is only a start and not a suggestion of a finish." Every graduate ought to feel that as he leaves school he is entering upon a " post-graduate course," which is to last the rest of his useful life. I have been following such a course for the last twenty years, and I hope it may last twenty or thirty years longer.

I have confirmed by repeated observation the truth of Dr. Goldsborough's remark about the applicant for a position. The individual often spends too much effort in trying to get a position and too little effort in trying to keep it. I think it far better to spend time, even years, in getting ready to *fill* a good position than in seeking for it. The old proverb says: " He who deserves success shall command it." The engineers who are successful, (I mean as engineers, not necessarily as money-makers), carry out, as a rule, the spirit of that proverb; they symbolize its realization. They typify and dignify the doctrine that the " position should seek the man." They bestow their best efforts upon all their work, whether the task be imposing or humble. They are content to do little things long, until they can do them well, and to learn through them, and to progress from them to greater things. The time ultimately comes when they can utilize their knowledge to advantage and with financial profit; and oftentimes the longer the opportunity has been in coming, the better and more satisfactory it proves to be. Luck has far less and merit far more, to do with these things than is generally believed. Just as, in physics, water proverbially seeks and finds its level, so in human affairs, there is a force tending ever to place individuals at the proper levels. Shakespeare has expressed this force in terms of a " divinity which shapes our ends." Reverting again to Victor Hugo's quaint phrase, I would state that our " ends " are " shaped," oftentimes, not " because of " but " in spite of " our efforts to " rough hew them as we will." We often find the man whose object was pelf, fail to get that which

was his sole object, whereas the individual whose primary aims are merit and worth, often " gets the emolument besides."

In conclusion, I may say that I am highly impressed by the general programme of " reformed " engineering education outlined in Prof. Esty's paper, in the concluding paragraph. I am also glad to find some authoritative expressions of sentiment favoring better and broader preliminary general education, more thorough even if less extended theoretical and practical technical training, and in general, commending the process which leads to the best ultimate rather than to the most immediate results.

MR. SKINNER:—As a representative of the engineering department of a large manufacturing concern, I wish to agree most heartily with all that has been said in favor of the broad education of the engineer. I fully appreciate the difficulty mentioned by Prof. Goldsborough, that many students, particularly in the West, are, for financial reasons, unable to continue their studies for the length of time necessary to get this broad education. I am surprised, to say the least, at the grounds taken by Mr. Raymond, that specialization should begin so early. I think we are all more or less familiar with the phenomenon of the aging of steel after it is annealed. I am sure that men with such training as Mr. Raymond advocates will age very rapidly, indeed, when put through his annealing process.

PRESIDENT STEINMETZ:—Gentlemen, discussion is still in order. I call upon Mr. R. W. Pope, who was going to give a few minutes' talk.

SECRETARY POPE:—I just wish to say that I have not sufficient command of language to express my appreciation of the attendance here, and what the people of my native town have done for the engineers, and the fact that we have been brought together under such delightful circumstances. I obtained Mr. Arnold's permission before he left, to join me in support of Mr. Mailloux's argument that we could not learn too many languages, and if there is one thing that Mr. Arnold and I regretted, it was that we knew so little of French when we were together in Paris.

In my school days, which with the exception of one year were passed in Great Barrington, a college education was scarcely thought of unless the pupil intended entering the profession of law, medicine or the ministry. My school education ended with my fourteenth year. I have always regretted that this was the case, as I now realize that there must be a feeling of satisfaction due to college training that has been lacking in my own experience. I have, however, trained myself to believe that the education of a man is a most important step in his career, but that the result depends very largely upon the quality of the material to be dealt with. It has been stated in this discussion that the profession of electrical engineering dates back only about fifteen years, and I have therefore thought it of interest to include in my remarks an editorial written by me seventeen years ago which appeared in the *Electrician and Electrical Engineer*, October,

1884, as indicating the views of one who at that time had been engaged in railroad and telegraph work twenty-five years.

TECHNICAL EDUCATION.

"There is no more important question in the whole range of social topics than that of education, and public attention has been directed to it both in Europe and America, for the purpose of devising, if possible, some system which would more effectually teach what the pupil may be expected to practice when he reaches maturity. The fact that a student when obtaining a classical education devotes to that work the very years when he should be gaining a practical knowledge of the handicraft by which his living must be earned, has in a measure, obliterated the old idea that every boy with brains *ought* to go through college. The value of such a training is by no means to be underrated, but it should not be exacted without proper consideration of the future, and every parent should be able to discern whether a boy of fourteen has a decided leaning toward the so-called learned professions, science or mechanics. Whatever walk in life he may finally travel, he may not prove eminently successful, even if meritorious. Success, from a worldly point of view, is a matter of chance, as well as of merit; but moderate success, which brings contentment and happiness to thousands of humble homes, is but the application of honest industry and judicious economy to that line of duty which has finally been selected as the means of livelihood. This is the fundamental idea of a technical education. To what extent it should be carried out is still a matter of dispute. There can be, however, no good reason advanced why a bricklayer may not graduate from his special school, as well as a physician from a medical college. Practically the artisan would be the more perfect production of the two, for the reason that the elements that he deals with do not present such a variety of phases which require far more practical experience. In discussing the merits of technical schools, both their opponents and advocates are prone to lose sight of the value of experience. The amateur artisan, as well as the college graduate, in cutting loose from their Alma Mater enter the professional arena, and instead of humbly seeking further light as to the mysteries of their craft, endeavor to parade their superior attainments, get snubbed for their pains, and at once build up a feeling of enmity which years of association may not eradicate. The student should be constantly impressed with the idea that he is not *learning* a trade or profession, but merely learning how to begin, and then when he enters the vast field of labor, it will be in the more dignified garb of a skillful apprentice, rather than that of a bungling journeyman. He will thus escape much of the drudgery which usually falls to the lot of the youngest employes, for the reason that his time will be too valuable to be devoted to such service. Here it may be remarked that much of the animosity that exists against the introduction of new labor in the trades, is caused by the plac-

ing of incompetent hands, at low wages, in positions which they are not qualified to fill. Employers are also responsible for the existence of considerable ill-feeling, by not properly appreciating the value of long experience in certain branches of the service. A larger proportion of the spirit of humanity infused into those years of toil would, beyond question, materially increase the profits of nearly every branch of business."

In re-reading the above under the light of later experience, and in view of to-day's discussion, I will merely add that I take pleasure in admitting the advantages and satisfaction to be derived from a classical education, supplemented as far as possible with a knowledge of modern language, in which I should certainly include French, German and Spanish. My experience teaches me that the student should pursue his studies as early as possible, for unless he denies himself the opportunities offered for recreation and social intercourse, he will find that owing to the demands upon his energy required in his regular employment, he will find less and less opportunity to study. My early telegraphic work, followed by years of editorial experience, and accompanied at all times with reading of the best English literature, has forced upon me what little knowledge of our language I possess, and at the same time taught me that a more thorough general education would have established a more satisfactory foundation, which I would urgently advise young men to obtain, and the neglect of which is to-day inexcusable.

MR. RAYMOND:—I think the paper has had an injustice done it. These gentlemen apparently assume that as soon as men graduate from college that all study ceases. I propose to drop during the college course those studies that will be taken up by the students themselves later, such as literature and history. A man can read history without a trained professor to assist him. One who has come out of college and has studied for four years is not going to stop as soon as he graduates. It would undoubtedly be interesting to study astronomy during the college course, but we must agree there is no time to take it up. Many of us since leaving college, may, however, have studied it quite thoroughly. I repeat, why not drop the studies that can easily be taken up after graduation and concentrate on those most urgently needed in our profession and in a large number of cases not properly taken up during the college course.

[COMMUNICATED AFTER ADJOURNMENT BY B. A. BEHREND IN DISCUSSION OF PAPER BY M. LEBLANC.]

The result of M. Leblanc's paper can be obtained in a very simple way by directly considering the case of a transmission line having no ohmic resistance but only distributed capacity and self-induction. I will briefly outline how to obtain this result, leaving to a special paper the highly interesting subject of the phenomena of long transmission lines treated in an elementary way.

The differential equation for a long transmission line having distributed capacity and distributed self-induction is readily obtained from our figure. Let C be the mutual capacity per unit length, and L the inductance per unit length of the two wires, then the charging current per unit length is

$$i = 2\pi n C v \tag{1}$$

where v is the potential between the wires. Setting $2\pi n C = a$, for the sake of simplicity, we have

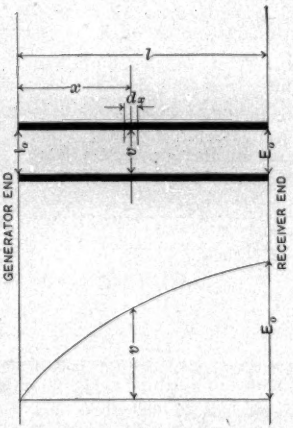


FIG 1.

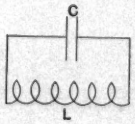


FIG. 2.

$$i = a v \tag{2}$$

The e.m.f. of self-induction is equal to

$$e = 2\pi n L i \tag{3}$$

Again, setting $2\pi n L = b$, we obtain

$$e = b i \tag{4}$$

Let us investigate the distribution of potential along the line on the supposition that the potential at the generating end is

zero, then the distribution of potential thus obtained will be identical with the distribution for the fundamental of the natural vibration of the line.

We have for the charging current in the element dx.

$$di = a v \, dx \tag{5}$$

The inductive drop in the line is

$$dv = -b i \, dx \tag{6}$$

Hence, by differentiating (6) and substituting in (5) we obtain,

$$\frac{d^2 v}{dx^2} = -ab v \tag{7}$$

The solution of this equation is

$v = A \sin \kappa x + B \cos \kappa x$, for by differentiating

$$\frac{dv}{dx} = \kappa A \cos \kappa x - \kappa B \sin \kappa x$$

$$\frac{d^2 v}{dx^2} = -\kappa^2 A \sin \kappa x - \kappa^2 B \cos \kappa x$$

$$\frac{d^2 v}{dx^2} = -\kappa^2 v$$

Therefore, $\kappa^2 = ab$, and $\kappa = \sqrt{ab}$ (8)

For $x = 0$, $v = 0$, by our assumption, hence

$$A \sin \kappa x = -B \cos \kappa x$$

$$B = 0$$

Therefore,

$$v = A \sin \kappa x$$

For $x = l$, $v = E_0$, hence

$$E_0 = A$$

The potential at different points of the line is thus given by the equation,

$$v = E_0 \sin \kappa x \tag{8}$$

We obtain the maximum value of v for

$$\sin \kappa x = 1,$$

and, therefore, the most dangerous case exists for a line whose length is such that

$$\kappa l = \frac{\pi}{2}$$

or, substituting for κ its value $\sqrt{ab} = 2\pi n \sqrt{LC}$, we obtain

$$l = \frac{1}{4n\sqrt{LC}} \tag{9}$$

Now, let us see what relation the length of the line thus determined has to the wave-length. It can easily be proved that the velocity of an electro-magnetic disturbance is given by

$$V = \frac{1}{\sqrt{LC}} \tag{10}$$

L and C being the inductance and capacity per unit length of the line in electro-magnetic measure.

Let λ be the wave-length, then we have

$$\lambda = \frac{V}{n} = \frac{1}{n\sqrt{LC}} \tag{11}$$

and substituting in (9)

$$l = \frac{\lambda}{4} \tag{12}$$

which is M. Leblanc's result arrived at in a strictly correct but simple manner.

I need hardly remark that from equation (8) follows that if κl is equal to $3\pi/2$, $5\pi/2$, $7\pi/2$, etc., a dangerous state is obtained.

From (9) follows that the fundamental of the natural frequency of the line oscillation is

$$n = \frac{1}{4l\sqrt{LC}} \tag{13}$$

It is interesting to compare this result with that of a condenser and an inductance connected in series. The natural frequency of such a system (Fig. 2) can easily be obtained by the consideration that the potential difference between the condenser plates must be equal and opposite to that at the terminals of the inductance, hence

$$2\pi n L i = \frac{i}{2\pi n C}$$

From this follows:

$$n = \frac{1}{2\pi\sqrt{LC}} \qquad (14)$$

The discharge frequency of a long line with distributed capacity and self-induction is therefore greater than if the capacity and self-induction were concentrated as in Fig. 2.

The subject is treated by Dr. Bedell and Dr. Crehore, and by Mr. Steinmetz, and my remarks are made with the sole purpose of showing a short cut to the known results.

NORWOOD, O., July 1, 1902.

[COMMUNICATED AFTER ADJOURNMENT BY B. A. BEHREND IN DISCUSSION OF MR. STEINMETZ'S PAPER ON THE "THEORY OF THE SYNCHRONOUS MOTOR."

Mr. Steinmetz calls the quantity $\frac{1}{2} m v^2$ by the name of "mechanical momentum," but since the time of Newton the term "momentum" has been used to designate the product $m v$, and we speak of the "conservation of momentum," and of the "conservation of angular momentum," meaning thereby the conservation of the product $m v$, as, for instance, in the case of impact. Since the formulation of the principle of the "conservation of energy," we have been accustomed to call the quantity $\frac{1}{2} m v^2$ the "kinetic energy" of the body in motion, and we should like to ask why Mr. Steinmetz deems it necessary to change, without explanation, a nomenclature which has been used by Helmholtz, Kelvin, Maxwell, Rayleigh and others.

NORWOOD, O., July 1, 1902.

[COMMUNICATED AFTER ADJOURNMENT BY MR. CALVERT TOWNLEY IN DISCUSSION OF MR. A. H. ARMSTRONG'S PAPER, PAGE 569, MAY ISSUE.]

I have read with much interest Mr. Armstrong's account of his various investigations, which involve and represent an enormous mass of painstaking mathematical calculations. His graphic representations of the results obtained are clear and concise, and will furnish material for much contemplation and study to any one interested in following out the possibilities involved by changing the numerous railway motor variables between widely separated limits.

His individual conclusions given as interpreting the various curves plotted are clear and well stated, but there is one general conclusion not deduced directly from the calculations which does not seem to me proved, and with which I am unable to entirely agree. Mr. Armstrong states:

"As a result of considerable investigation along these lines, the writer has not arrived at any commercial rating of a railway motor which serves its purpose better than the one-hour test now universally used. Admitting that such a test does not give the comparative size of different motors, it does serve the

purpose of largely determining its commutating qualities and possesses the advantage of being commercial. Unless a rating can be proposed which will indicate accurately the relative size of motors, the present method of one-hour rating possesses advantages which would hardly warrant its being superseded."

Summing up briefly, the plotted results of the calculations show that there are some thirteen or more variables which affect the service capacity of a motor, that there is no short-cut method of rating a motor which takes into account all these variables, the inference being, therefore, that neglecting so to do is likely to lead to fatally erroneous conclusions. In the face of this set of conditions it is not clear to me what can justify the one-hour horse-power basis of rating motors which takes account of practically none of these variables. The advantages of the one-hour horse-power rating of motors are stated as follows:

" It does determine the mechanical qualities of the motor, as the one-hour test is generally very severe, and it also affords a means of observing commutation at the maximum current for which the motor will probably be called upon in service operation."

It is not clear to me what is meant by the " mechanical qualities " of the motor. This term cannot refer to the mechanical strength of the various parts of the motor, as the mechanical strains in a shop test of this nature are of course very light compared to the strains of service. The fact that a motor, resting on a stand in the shop, would take a certain amount of current for an hour, would hardly be held as any measure of its mechanical strength for its service on a road.

With reference to commutation, the comparison is hardly less decisive, as a modern commercial motor which did not at least commutate well on towards twice the current represented by its one-hour horse-power rating would hardly find much favor. There are two other reasons, not given in the paper under discussion, but sometimes advanced for the retention of the one-hour horse-power rating; first, that it is an established basis of comparison broadly known and used by railway men, and second, that the use of the term horse-power affords the advantage of a well-understood unit which is comprehensible alike to engineers and laymen. The first of these reasons is sound so far as it goes, but the same reason is always offered against any change in standards or nomenclature, and is scarcely sufficient for adhering to a method otherwise undesirable. The second reason has always appeared to me an argument against itself; *i.e.*, that the very use of the word " horse-power " as applied to a one-hour rating is misleading, in view of the fact that this term is broadly associated with the capacity of apparatus in continuous service. I well remember the strongly expressed disappointment and disgust of a prominent railway official who had been talking about the "horse-power " of railway motors, when he learned that the term meant capacity for one hour only,

whereas he operated his lines twenty-four hours a day. If there is a good reason for adhering to the term "horse-power," it might better be applied to a rating corresponding to the duty which the motor would perform continuously.

In the light of all of the foregoing, a plea for the retention of the one-hour horse-power rating would seem to ask that as we cannot get a short-cut rating which will express with absolute theoretical accuracy all of the comparative features of two or more motors, let us use one which is as inaccurate as possible.

It is undoubtedly true that the increase in maximum and in schedule speeds, and also in the weight and amount of heavy traffic, which has been perhaps the most prominent feature of recent developments in electric traction, tends to aggravate the inaccuracies of short-cut comparison pointed out in this paper, and no one will gainsay the desirability of determining the adaptability of any particular motor to the service requirements for any particular installation with all the accuracy that is practicable, and is justified by the magnitude of the enterprise. In recognizing these facts, however, we should not forget that a very large proportion of the money which is invested in railway motors is by roads operating equipments of small or moderate capacity, operated at low or moderate speeds. For such roads it is frequently, one might almost say, generally impracticable to determine within accurate limits the service conditions described by this paper as necessary for the proper comparison of motors. It would, therefore, seem reasonable to determine within what limits a conclusion based on some short-cut method is likely to err, and in our methods to allow such a margin as will minimize the chances of any serious misfits It will hardly be disputed that if we cannot be absolutely accurate we should be as accurate as we can, and I for one should regard it as unfortunate should this INSTITUTE appear to the public committed to the statement that it is ordinarily impracticable to select a railway motor suitable to average service conditions without making a somewhat intricate comparison based on service data which it is impossible to obtain.

In this connection, the method of rating and comparing the service capacities of motors as proposed by Mr. N. W. Storer in articles entitled "The Capacity and Rating of Railway Motors," printed in the November 2, 1901, and January 5, 1902, issues of the *Street Railway Journal*, appeals to me as coming much nearer a useful method than the one-hour horse-power rating. The writer has had occasion to check the type of motor indicated by this method as best, with that shown most desirable by more intricate calculations obtained at considerable pains from service observations. In every case the motor selected by the Storer method has been a safe motor for the work, and very close in its characteristics to the calculated service conditions. On the other hand, instances are not lacking where selection on the basis of horse-power rating have produced results which were far from

satisfactory. Be that as it may, however, I cannot but believe that the general sense of the members of this INSTITUTE is that if we cannot be absolutely accurate we should be as accurate as we can.

[COMMUNICATED AFTER ADJOURNMENT BY MR. PHILIP TORCHIO IN DISCUSSION OF THE REPORT OF COMMITTEE ON STANDARDIZATION.]

In connection with the "Report of the Committee on Standardization," I would like to make a communication calling attention to the paragraph where the recommendation of insulation voltage tests for fields of synchronous motors and converters is given as follows: "Synchronous motor fields and fields of converters started from the alternating current side—5,000 volts." It is my understanding that the Committee here recommends that *all synchronous motor fields* should be insulated for a test of 5,000 volts, but in the past some parties interested in this type of apparatus have intrepreted the recommendation of the Committee to apply only to synchronous motors *started from the alternating current side*. This point should be made clear so as to avoid misinterpretation. A statement reading "Fields of all synchronous motors and fields of converters started from the alternating current side—5,000 volts," would not be open to discussion.

It may now be too late for making any amendment to the report which has already been acted upon, but I make this suggestion for future consideration.

An address delivered at the 168th Meeting of the American Institute of Electrical Engineers, New York, September 26th, 1902.

PROPOSED DEVELOPMENTS OF THE INSTITUTE.

An address

By Chas. F. Scott, *President.*

Gentlemen:—To-day your newly-elected officers enter upon their duties, and another year begins. Before entering upon the routine of our regular work, let us pause to consider the functions of our Institute, its present status and its future possibilities.

The position occupied by the electrical engineer is unique. The science which underlies his work is most fascinating and most fruitful. Its applications are not confined to a limited field. There is scarcely a branch of human activity that has not received its quickening touch. So rapidly have electrical novelites become commercial necessities and simple experiments evolved great systems that a new branch of engineering has been developed in a score of years. The scope of the electrical engineering profession has developed from trivial beginnings until it includes works of the greatest diversity and magnitude and far-reaching consequences, in industrial, commercial and social life. This development has been the result not of mere chance, but of a combination of favoring conditions. Faraday and Maxwell laid the foundations of electrical science and the general mechanical, industrial and scientific evolution of the nineteenth century gave the necessary opportunity and impetus to its commercial application. Electricity is usually a means, an agency, and is not in itself an end. In order that electricity may be applied, there must be that to which it can be applied. The electric motor, for example, would be of little consequence if there were no field for it—if there were no machine-shops or mills, no elevators or street cars. It is

because the steam engine has for a century been training men to use mechanical power, and because the existing methods of transmitting and distributing power have such fixed and narrow limitations, that the electrical system has so quickly taken its place between engine and lathe, between the waterfall and the loom. It is because the science of electrochemistry was advancing that the dynamo found a place in electrochemical industries and, in turn, cheap electrical energy has accelerated electrochemical development. It is notable that the greater part of the power developed at Niagara Falls is used in electrochemical and allied processes, in the manufacture of aluminium, carborundum, sodium, chlorine, caustic soda, calcium carbide, phosphorous, graphite and barium hydrate; while in almost every case even the discovery of the process itself, as well as the development of the industry, has occurred since the work upon the power plant was begun.

It is a hackneyed theme—the infancy of electricity; and yet to obtain a just view of his position the electrical engineer must realize how brief compared with other branches of engineering is the experience upon which his work is based. Even the man who has been called the "Father of Electrical Engineering," whose theoretical and mechanical skill made possible the success of the ocean cable, is still a vigorous worker, and quite recently the INSTITUTE was privileged to tender him a reception. I refer, of course, to our distinguished Honorary Member, Lord Kelvin. It is not yet twenty-seven years, the age required for full membership in the INSTITUTE, since the Centennial Exposition gave an impetus to electrical invention and the telephone was made public. It was not until 1884, the year of the Philadelphia International Electrical Exposition, that measures were taken for establishing a national organization among electrical men, and the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS was established. Its first President, Dr. Norvin Green, and half of its vice-presidents and managers were identified with the telegraph. The practical electricians of those days were telegraph men, but now a new generation has arisen to whom the click of the sounder is unintelligible.

The past fifty years and notably the past decade have witnessed a general development of such magnitude that it marks an epoch in the World's history. And in this development, electricity has been foremost. I will not attempt to recount and catalogue what has been accomplished, in how many ways

electricity has proven useful, the various purposes for which it is employed in industrial and manufacturing enterprises, nor to what extent the telephone, telegraph and cable have affected domestic, commercial, social and national life; I will not mention the results which the railway motor in city, suburban and interurban service is effecting in the cheapening of travel and the redistribution of population; I will not dwell upon the far-reaching effects in the economic world of an agent which makes possible the combination of formerly diverse interests by operating in one great system local and interurban railways, mills, shops, elevators, street lighting and indoor illumination; nor will I even attempt to sum up all these achievements and estimate by how much the results of human activity are increased through the agency of electricity. The point I do make is the rapid growth and the magnitude of the work and the far-reaching responsibilities which have so quickly devolved upon the electrical profession.

Consider for a moment the financial aspect. It is estimated that the total investment in electrical applications outside of telegraphy and telephony at the time this INSTITUTE was founded, did not exceed $1,000,000. At the present time the estimated capitalization of electrical applications in the United States approximates $4,000,000,000. In other words, electricity represents a value about one-third as great as that represented by the investment in our steam railway systems. Speaking generally, this enormous expansion has been made possible by the electrical engineer, and furthermore the successful outcome of these investments depends upon his work. Even these figures do not fully measure the vast responsibilities which are entrusted to the electrical engineer, since they take no account of the importance of his work in the many industries and enterprises which use electrical apparatus in a merely subsidiary or auxiliary way.

The work which the future has in store for the electrical engineer seems even greater. Scarcely a plan for future progress is proposed either by the practical and conservative business man, manufacturer or engineer, or by the sanguine promoter or the imaginative writer who portrays an Utopian civilization, which does not involve some application of electricity.

We are now at a time of general prosperity. Will this continue? Is prosperity a normal condition, or are successions of prosperity and depression inevitable? Continued prosperity requires high efficiency. Effort must not be wasted or dissipated.

The ordinary activities and functions of industrial and commercial life must be efficiently performed, and energy must not be lost through great undertakings which fail in the execution, or accomplish no useful result. Imagine the results had the hundreds of millions of pounds expended by England on the South African war been devoted to the development of the country, by establishing electrical railways and lighting and power plants. Consider what a drain upon the resources of a country both in wealth and in men, are a large standing army and navy. Even granting that wars have been necessary factors in the world's history, and that on the whole they have been beneficial, nevertheless they indicate how vast are the forces which have directly retarded rather than advanced material prosperity. There is no doubt but that the forces at hand are ample to maintain a constantly increasing condition of prosperity if they be wisely directed. A grave responsibility rests upon the intelligent, the wealthy and the directing classes.

As a factor in maintaining prosperity, the work of the electrical engineer is of great consequence. Applied electricity so increases the efficiency of industrial and commercial life that a given expenditure of energy can produce greater results in less time. The electrical engineer is called upon to advise and direct in many large undertakings and upon the soundness of his judgment depends success or failure. Since electricity occupies so vital a place in the affairs of the present, and will be an increasing element in those of the future, the electrical engineer must be an important agent in avoiding depression and maintaining prosperity.

If we were to consider further the indirect as well as the direct relations of the electrical engineer to industrial and commercial and social interests we would be more deeply impressed with the responsibility of his part in the world's work In a profession where there are so many workers, where the majority of them are young men, where their work is so closely connected with scientific investigation and with what is being done in allied professions, when the rate of advance is so great in scientific discovery, in invention, in application to processes which are new and to undertakings of increasing value, and particularly in a country which is recognized as foremost in electrical development, there is a unique field for a national organization such as the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS. In a profession whose interests are so diversified and so extended,

workers should be brought together. They should have a common meeting place. Here discoveries may be announced, inventions described, engineering schemes criticized and new undertakings presented and discussed. Here the student and professor, the investigator, the inventor, the manufacturer, the operator and the consulting engineer may meet upon common ground. The engineer who is tempted to ridicule scientific work finds that it is the foundation upon which his own work rests. The professor who regards slightly the work of the designing or constructing engineer may find that his own cherished formulæ are derived from the rules and contain the constants which the practical man has determined for himself. Association leads to mutual understanding, it curbs eccentricity and one-sided development, and promotes symmetrical advancement.

It is the function of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS to bring individual workers into a common unity, to join them in a community of interest—a fraternity which is called the electrical engineering profession. It should place the profession of electrical engineering above suspicion of corruption and chicanery and should call for high standards of dignity and honorable accomplishment. It should discountenance the spirit of blind partisanship and of depreciation of others' efforts among those who are divided by commercial interests, whether they represent competitors or buyer and seller. While each has his individual interests, there is a general interest which is common to all. All share in that which discredits the profession as well as in that which elevates and advances it.

It is the function of the INSTITUTE to bring together continually the diversified achievements of many workers, which taken altogether constitute a single total of accomplishment—a total which is called progress. It should discriminate between that which is substantial and that which is not. It should place the stamp of recognition and approval upon all that is meritorious and marks an advance in the art.

It is the function of the INSTITUTE to take the lead in such measures as will promote the general interests of the profession and the efficiency of electrical work.

In the past the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has represented the profession and advanced its interests in various ways:

It has taken a prominent part in establishing uniform insurance rules in a National Code.

It has been conspicuous in representing American engineers at international expositions and international congresses both in America and abroad. In the same connection it has been active in establishing international standards, and through its advocacy the name Henry, in honor of an American electrician, has secured a place in the list of electrical units.

It prepared in 1890 the standard wiring table for lighting and power purposes, which has been of great service in standardizing electrical calculations.

It has established a code of standardization covering names, definitions, methods of rating, tests and the like, which is of the greatest service in unifying and simplifying electrical practice.

It has established through the generosity of a few individuals a library which in historic value is unequaled.

It has brought electricians together in annual conventions and in monthly meetings, it has stimulated activity through papers and discussions which have dealt with vital problems, it has developed in eighteen Volumes of TRANSACTIONS a panoramic history of American Electrical Engineering.

Let us now turn our attention to the future and consider the specific ways in which the work of the INSTITUTE may be advanced during the coming year:

1. The membership should be increased. The power and influence of the INSTITUTE is dependent upon the number, character and activity of its members. There are many engineers eligible to membership who are not members, because they do not fully appreciate the scope and the work of the INSTITUTE. There are many electrical workers who would become worthy associate members if they realized the value of connection with the INSTITUTE.

Is it not the privilege and the duty of an electrical engineer to give his best support to the INSTITUTE which stands for the highest interests of his profession? Are not the advantages which connection with the INSTITUTE affords such that no progressive engineer can afford to be without them? If these things are so, then it rests upon the present members to build up the INSTITUTE by making its work known to those who should become members.

During the past year the membership increased 25 per cent. and reached 1,546. This is less than one-half the membership in the British Institution of Electrical Engineers. If AMERICAN INSTITUTE membership bore the same relation to the kilowatt

capacity of the electrical power-stations of the country as does that of the British Institution, our membership should be 25,000.

There are to-day cities in which are located engineering schools and large electrical interests, which have but three or four members. Five States east of the Mississippi River have but one or two members each, and there are three of the New England States that have but three members each.

2. Papers and discussions should be contributed from a larger proportion of the membership. The transactions of the INSTITUTE should be a record of the advance in electrical work, and should contain only that which is of material value to the advancement of the art. I submit that even their present high standard does not adequately represent American electrical progress. If it is true that our papers do not fully present the advance thought and best achievements of the time, it is simply because our advance workers do not contribute more.

Material may be presented in formal papers, in original communications or in discussion. Some subjects do not provoke general discussion; others depend for their value upon the experience or the opinions of a large number of members. While the INSTITUTE is not as a body responsible for the statements or the opinions of its members, there is nevertheless an obligation resting upon its members not to leave unchallenged any inaccurate and misleading statements.

Our last volume shows that 5 per cent. of the membership took part in the meetings, and that 2 per cent. furnished papers. Of these papers 10 per cent. came from miscellaneous sources, 20 per cent. came from college professors, 25 per cent. from operating and consulting engineers, and 45 per cent. from engineers connected with manufacturing companies.

These figures indicate that electrical matters are advancing so fast that even the teachers in the great technical schools fall behind the pace, because the problems come first to the manufacturer. To the manufacturing companies must be given credit for substantially advancing scientific investigation as well as practical development.

Further examination of the last annual volume shows that although one-fourth of the members reside in New York and the monthly meetings are held there, yet only one-fifth of the papers were presented by New York members. The INSTITUTE is national in its scope, and there should be united effort through-

out the entire membership to increase the quantity as well as the quality and the usefulness of its published proceedings.

3. Local meetings of the INSTITUTE in various cities will broaden the interest in its work and generally extend its benefits. Some local organizations have been formed, but this department of our work should be greatly extended. While such organizations should be conducted in harmony with the general methods and purposes of the INSTITUTE, synchronizing as far as practicable with its general meetings, they should also become "self-exciting" centers of local electrical activity. There is so much material available and there are so many subjects of local and general interest that a small amount of well-directed effort in organization will produce great results.

4. Universities and technical schools with electrical engineering departments may organize local meetings of the INSTITUTE which would be of benefit to both instructors and students in keeping them in touch with the most recent developments and practice in electrical work. Meetings may be under the direction of the professor of electrical engineering and may be conducted in various ways to conform best to the local conditions. Local INSTITUTE members may join with the school meetings. A school should be the natural center for engineers of its vicinity. It supplies a suitable meeting place, and the discussion of INSTITUTE papers by engineers, instructors and students should be of benefit to all. In the thesis work of students the INSTITUTE may be helpful also in recognizing and publishing in abstract or in full, theses which are noteworthy. This would give an impetus to the preparation of theses and wholesome rivalry among different institutions, and would add to the value of our Transactions.

The proper education of the engineer is a problem to which various solutions are offered. All however, will doubtless agree that the profession has already reached a stage and is advancing so rapidly that the purely "practical man" cannot hope to maintain himself in the front rank. The rate at which development is progressing demands a thorough grounding in fundamental principles, in order to impart the power for grasping and meeting new conditions. My predecessor spoke truly when he said that the primary aim of the educational institution should be to give the young engineer "a thorough understanding of the fundamental principles of electrical engineering and allied sciences, and a good knowledge of the methods of dealing with engineering problems." The best education is that in which

theoretical training in fundamental principles predominates. The true function of practical work in a broad engineering education is not to produce skilled workmen or full-fledged engineers, but it is to supplement theoretical work, making it definite and certain, so that the student may properly assimilate the instruction which he receives. Again, a student should not make his mind a storehouse of facts, but he should learn where facts and information can be obtained, and how to use them.

The principal purpose for bringing the work of the INSTITUTE directly to the student is to enable him to keep in touch with actual things and give him a definite idea of the kinds of work which lie before him, and for which he is preparing. Fortunate will it be if we can lead him to see that in the development of an electrical engineer there should be something besides technical training—that logical thinking and clear expression and general culture are indispensable in a profession that is closely related to so many departments of science and engineering as well as industrial and commercial and social activity, and that he must be a broad man with a broad educational foundation, who would aspire to the fullest usefulness and success.

5. The collection of engineering data and the establishment of standard practice in electrical engineering is one of the important functions of the INSTITUTE. The present years are formative years. Electrical engineering is crystallizing. Electrical theory and laws and electrical measurements are more definite than those relating to the allied professions; for example, compare the accuracy in the predetermination of the efficiency of a dynamo with that of an engine, or the ease and precision of measurement of dynamo output by a wattmeter with that of an engine by a mechanical dynamometer or brake. Electrical engineering practice, however, is now being established. The apparatus and the methods, both in detail and in general, which characterize present work are radically different from those of five or ten years ago. It is of the highest importance to the profession that definitions and principles and laws pertaining to engineering practice should be determined and adopted as rapidly as circumstances will permit. General investigations should be made in various lines of electrical engineering work, not primarily for the purpose of devising theoretical standards or undertaking original investigation, but for the purpose of determining what is best in present practice, and of formulating and crystallizing it into what may be recognized as standard practice.

We must not fail to realize the value of standards. An English engineer in a distant part of the British Empire in specifying the apparatus for a large electrical railway, strongly recommended that American standard apparatus be purchased as "England has no standard." In Europe to-day there is a confusion of systems and frequencies and voltages, and a wide diversity in types of construction. Many foreign engineers pride themselves on devising that which is novel, instead of adapting that which is standard. American engineers are not divided by nationality and by language as are those of Europe; they have that unity in which there is strength; they appreciate the advantage of adhering to standard practice; they realize that the manufacture of dynamos and motors, as well as of shoes and clocks, of engines and bridges will be cheaper and quicker if made in quantity.

Do you realize the relative magnitude of American electrical work? The United States with only one-fifth the population of Great Britain and Europe has two and one-third times the kilowatt capacity in power-stations, and three and one-half times the mileage of electric railways. The power-houses in operation and under contract in New York City would replace all the central stations for lighting and power in Great Britain or in Germany; they would operate all the electric railways of Great Britain and Europe combined; one alone would be sufficient for the railways of Germany and the output of a single generator would run all the railways of Switzerland.* Although some foreign engineers are still in doubt as to the practicability of the rotary converter, yet the output of American rotary converters is sufficient to operate all the railways in Great Britain and Europe combined. American designs, methods and practice are being introduced into half-a-dozen factories in foreign countries. Electrical progress and leadership can be promoted by this INSTITUTE, as it draws together and unites the efforts of electrical workers and as it aids in establishing the standards for the future. Standards are not to prevent progress, but they are to make definite the steps already taken and they are the foundation for advancement.

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* See "Some Comparative Approximate Figures of Electric Light, Power and Traction Systems in European Countries and in the United States of America at the Present Day," Philip Dawson, *Engineering Magazine*, February, 1902, page 712.

6. Our library merits a cordial support. The policy decided upon by the Library Committee is to place upon our shelves every book relating to electricity in the English language, and every book of any value in the French, German and other languages. Let all who are able, coöperate in this important work of building up a complete reference library.

Through good fortune and the generous assistance of Dr. S. S. Wheeler we have the Latimer Clark library as a foundation. Mr. Carnegie's kindly contribution has enabled the library to be catalogued and otherwise made useful. Various members, notably Messrs. Mailloux, Hutchinson, Wetzler, Arnold, Keith, Caldwell, Jenks, Fish and Clarke, as well as the American Bell Telephone Co., The New York Electrical Society, and others, have contributed valuable sets of books, such as the proceedings of scientific societies, the records in patent litigation and the like. At least one member has provided by his will that a part of his technical library shall pass to the INSTITUTE and another is proposing an endowment for the future continuation of the sets which he has presented.

The preceding sentence was written yesterday. I am authorized by the Council to state the contents of a letter received to-day from Mr. W. D. Weaver, the Chairman of the Library Committee—to whose efficient services the development of the Library is due. This letter reports the receipt of a check from Mr. Mailloux to be used as an endowment for continuing subscriptions to several of the valuable sets which he has presented to the Library. Among the books, a thousand or more, which he has presented, are some rare series, some of which have been secured at considerable cost, others by rare good fortune. Our Library is already assuming a high rank among electrical libraries, and even among general technical libraries.

7. Permanent quarters for the INSTITUTE should be an object of plans and anticipations. An organization which is so closely connected with so many vital interests of such vast commercial value and which possesses such possibilities for promoting the best interests of the profession should not be hampered for want of the most convenient accomodations. Personal acquaintance and social intercourse are influential factors in unity of sentiment and of action. Our library is all but inaccessible in its present cramped quarters which do not permit normal growth.

8. Coöperation with similar institutions in other countries will

be mutually beneficial in various ways. In certain lines they may learn from us, but there is a great deal that we can learn from them.

In addition to general coöperation such as is promoted by international congresses, much is to be gained in less formal ways. For example, different institutions may at times discuss the same subject. Again, they may do a great service to electrical progress by harmonious working in the adoption of standards. The members of one institution may broaden their outlook by becoming members of other bodies. It is the hope and expectation of our INSTITUTE to have as its guest, within the next few years, the Institution of Electrical Engineers of Great Britain. The scope of our profession is world-wide. Let us welcome this coming opportunity to extend our acquaintance and broaden our ideas.

In conclusion, I have realized the responsibilities which rest upon the President of this INSTITUTE, and it was with reluctance and misgiving that I yielded to some urgent friends and consented to become a candidate. I fully appreciate the confidence you have expressed by your votes and I now ask your coöperation in continuing the high standard of work attained during the past year under my honored predecessor, whose able and enthusiastic efforts have awakened the INSTITUTE to new activity and usefulness.

The outlook is propitious. The Council of the INSTITUTE at its meeting this afternoon authorized the appointment of a Committee on Membership, also a Committee on Local Organization with authority to make immediate arrangements for the holding of local meetings. This Committee also has under its direction the proposed INSTITUTE meetings in connection with technical schools. A Committee on Theses was provided for to consider the relations of the INSTITUTE to this branch of student work. A Transmission Committee was provided for to collect data with respect to present practice in high tension transmission, particularly with reference to the construction of transmission lines and to formulate this data for the use of electrical engineers. It was recognized that this branch of engineering is advancing rapidly and that it merits special attention from the INSTITUTE in order that the best elements of present practice may be set forth. The standing Committees of the Council are taking up their work with renewed vigor.

If, my fellow-members, the objects of INSTITUTE endeavor which I have outlined are worth while, each of us can well afford to do his part towards realizing them.

A paper presented at the 168th Meeting of the American Institute of Electrical Engineers New York, September 26th, 1902.

WASHINGTON, BALTIMORE AND ANNAPOLIS SINGLE-PHASE RAILWAY.

BY B. G. LAMME.

The Washington, Baltimore and Annapolis Railway is a new high-speed electric line extending from the suburbs of Washington to Baltimore, a distance of about 31 miles, with a branch from Annapolis Junction to Annapolis, a distance of about 15 miles. The overhead trolley will be used, and schedule speeds of over 40 miles per hour are to be attained. This road is to be the scene of the first commercial operation of an entirely new system of electric traction.

The special feature of this system is the use of single-phase alternating current in generators, transmission lines, trolley, car equipment and motors. It constitutes a wide departure from present types of railway apparatus, and while retaining the best characteristics of the present standard D. C. motor system, the use of alternating current makes it possible to avoid many of the bad features.

The standard D. C. railway equipment possesses several characteristics which fit it especially for railway service. These characteristics have been of sufficient importance to overbalance many defects in the system. In fact, a far greater amount of effort and engineering skill has been required for overcoming or neutralizing the defects, than for developing the good features possessed by the system. By far the most important characteristic possessed by the D. C. system is found in the type of motor used on the car. The D. C. railway motor is in all cases a series-wound machine. The series motor is normally a variable field machine and it is this feature which has adapted the motor especially to railway service. Shunt-wound motors have been tried and abandoned. All manner of combinations of shunt,

series and separate excitation have been devised and found wanting, and in many cases the real cause of failure was not recognized by those responsible for the various combinations. They all missed to a greater or less extent the variable-field feature of the straight series motor. It is true that a variable field can be obtained with shunt or separate excitation, but not without controlling or regulating devices, and the variation is not inherently automatic, as in the series motor. Polyphase and single-phase induction motors do not possess the variable field feature at all, as they are essentially constant-field machines. They are equivalent to direct current shunt or separately excited motors, with constant field strength, which have been unable to compete successfully with the series motor. The variable field of the series motor makes it automatically adjustable for load and speed conditions. It also enables the series motor to develop large torques without proportionately increased currents. The automatically varying field is accompanied by corresponding variations in the counter e.m.f. of the armature, until the speed can adjust itself to the new field conditions. This feature is of great assistance in reducing current fluctuations, with a small number of steps in the regulating rheostat. Any increase in current, as resistance is cut out, is accompanied by a momentary increase in the counter e.m.f., thus limiting the current increase to a less value than in the case of a constant field motor.

Next to the type of motor, the greatest advantage possessed by the D. C. system lies in the use of a single current or circuit, thus permitting the use of one trolley wire. The advantages of the single trolley are so well-known that it is unnecessary to discuss them. For third rail construction, the use of single current is of even greater importance than in the case of the overhead trolley. It is seen, therefore, that it is not to the direct current that credit should be given for the great success of the present railway system, but to the series type of motor and the fact that up to the present time no suitable single-phase A. C. motor has been presented.

Some of the undesirable features of the D. C. railway system should also be considered. The speed control is inefficient. A nominally constant voltage is supplied to the car, and speed control is obtained by applying variable voltage to the motor terminals. This variation is produced by the use of resistance in series with the motors, with a loss proportional to the voltage taken up by the resistance. By means of the series-parallel

arrangement, the equivalent of two voltages is obtainable at the motor terminals without the use of resistance. Therefore, with series-parallel control, there are two efficient speeds with any given torque, and with multiple control there is but one efficient speed with a given torque. All other speeds are obtained through rheostatic loss, and the greater the reduction from either of the two speeds, series or parallel, the lower will be the efficiency of the equipment. At start, the rheostatic losses are always relatively large, as practically all the voltage of the line is taken up in the rheostat. For heavy railroad service, where operation for long periods at other than full and half speeds may be necessary, the rheostatic loss will be a very serious matter.

The controlling devices themselves are also a source of trouble. An extraordinary amount of time and skill has been expended in the perfecting of this apparatus. The difficulties increase with the power to be handled. The controller is a part of the equipment which is subjected to much more than ordinary mechanical wear and tear, and it can go wrong at any one of many points. The larger the equipment to be controlled, the more places are to be found in the controller which can give trouble. The best that can be said of the railway controller is that it is a necessary evil.

Another limitation of the D. C. system is the trolley voltage. Five hundred volts is common at the car and 650 volts is very unusual. By far the larger number of the railway equipments in service to-day are unsuited for operation at 600 volts, and 700 volts in normal operation would be unsafe for practically all. The maximum permissible trolley voltage is dependent upon inherent limitations in the design of motors and controllers. The disadvantages of low voltage appear in the extra cost of copper and in the difficulty of collecting current. In heavy railroad work the current to be handled becomes enormous at usual voltages. A 2400 H.P. electric locomotive, for example, will require between 3000 and 4000 amperes at normal rated power and probably 6000 to 8000 amperes at times. With the overhead trolley these currents are too heavy to be collected in the ordinary manner, and it is a serious problem with any form of trolley or third rail system which can be used. It is evident that for heavy service, comparable with that of large steam railways, a much higher voltage than used in our present D. C. system is essential, and the use of higher voltage is destined to come, provided it is not attended by complications which more than overbalance the benefits obtained.

A further disadvantage of the D. C. system is the destructive action known as electrolysis. This may not be of great importance in interurban lines, chiefly because there is nothing to be injured by it. In city work its dangers are well-known, and very expensive constructions are now used to eliminate or minimize its effects.

From the above statements it is evident that an A. C. railway system, to equal the D. C., should possess the two principal features of the D. C. system, viz: A single supply circuit and the variable field motor, and to be an improvement upon the D. C. system, the A. C. should avoid some of the more important disadvantages incident to the present D. C. railway apparatus.

The system must, therefore, be single-phase. The importance of using single-phase for railway work is well known. The difficulties and complications of the trolley construction are such that several A. C. systems have been planned on the basis of single-phase supplied to the car, with converting apparatus on the car to transform to direct current, in order that the standard type of railway motors may be used. Such plans are attempts to obtain the two most valuable features of the present D. C. system. The polyphase railway system, used on a few European roads, employs three currents, and therefore does not meet the above requirement.

The motor for the A. C. railway service should have the variable speed characteristics of the series D. C. motor. The polyphase motor is not suitable, as it is essentially a constant field machine, and does not possess any true variable speed characteristics. Therefore it lacks both of the good features of the D. C. railway system. A new type of motor must, therefore, be furnished, as none of the alternating current motors in commercial use is adapted for the speed and torque requirements of first-class railway service. Assuming that such a motor is obtainable for operation on a single-phase circuit, the next step to consider is whether the use of alternating instead of direct current on the car, will allow some of the disadvantageous features of the A. D. system to be avoided.

The D. C. limits of voltage are at once removed, as transformers can be used for changing from any desired trolley voltage to any convenient motor voltage. Electrolytic troubles practically disappear. As transformers can be used, variations in supply voltage are easily obtainable. As the motor is assumed to have the characteristics of the direct-current series motor, speed control without rheostatic loss is practicable when voltage control is

obtained. This combination, therefore, allows the motor to operate at relatively good efficiency at any speed within the range of voltage obtained. If the voltage be varied over a sufficiently wide range, the speed range may be carried from the maximum desired down to zero, and therefore, down to starting conditions. With such an arrangement no rheostat need be used under any conditions, and the lower the speed at which the motor is operated, the less the power required from the line. The least power is required at start, as the motor is doing no work and there is no rheostatic loss. The losses at start are only these in the motor and transforming apparatus, the total being less than when running at full speed with an equal torque. Such a system, therefore, permits maximum economy in power consumed by motor and control. This economy in control is not possible with the polyphase railway motor, as this motor is the equivalent of the D. C. shunt motor, with which the rheostatic loss is even greater than with the series motor.

The use of alternating current on the car allows voltage control to be obtained in several ways. In one method a transformer is arranged with a large number of leads carried to a dial or controller drum. The Stillwell regulator is a well-known example of this type of voltage control. This method of regulation is suitable for small equipments with moderate currents to be handled. The controller will be subject to some sparking, as in the case of D. C. apparatus, and therefore becomes less satisfactory as the car equipment is increased in capacity. Another method of control available with alternating current is entirely non-sparking, there being no make-and-break contacts. This controller is the so-called "induction regulator," which is a transformer with the primary and secondary windings on separate cores. The voltage in the secondary winding is varied by shifting its angular position in relation to the primary. With this type of voltage controller, very large currents can be handled, and it is especially suitable for heavy equipments, such as locomotives. It is thus seen that there is one method of control, available with alternating current, which avoids the inherent troubles of the D. C. controller. The induction regulator is primarily a transformer, and all wear and tear is confined to the supports which carry the rotor. Therefore the objectionable controller of the standard D. C. system can be eliminated, provided a suitable A. C. motor can be obtained. This ideal type

of controller is not applicable to the polyphase railway motor, in which speed control can be obtained only through rheostatic loss. The polyphase control system is even more complicated than the D. C., as there must be a rheostat for each motor, and two or three circuits in each rheostat. It is thus apparent that by the use of single-phase alternating current with an A. C. motor having the characteristics of the D. C. series motor, the best features of the D. C. system can be obtained, and at the same time many of its disadvantages can be avoided.

This portion of the problem therefore resolves itself into the construction of a single-phase motor having the characteristics of the D. C. series motor. There are several types of single phase A. C. motors which have the series characteristics. One type is similar in general construction to a D. C. motor, but with its magnetic circuit laminated throughout, and with such proportions that it can successfully commutate alternating current. Such a motor is a plain series motor, and can be operated on either alternating or direct current and will have the same torque characteristics in either case. Another type of motor is similar in general construction to the above, but the circuits are arranged in a different manner. The field is connected directly across the supply circuit, with proper control appliances in series with it. The armature is short-circuited on itself across the brushes, and the brushes are set at an angle of approximately 45° from the ordinary neutral point. The first of these two types of motors is the one best adapted for operation in large units.

This is the type of motor which is to be used on the Washington Baltimore and Annapolis Railway. Several motors have been built and tested with very satisfactory results, both on the testing stand and under a car. The results were so favorable that the system was proposed to the Cleveland Construction Company, representing the Washington, Baltimore and Annapolis Railway, and after investigation by their engineers, it was adopted. A description of the apparatus to be used on this road will illustrate the system to good advantage.

Single-phase alternating current will be suppled to the car at a frequency of 16⅔ cycles per second, or 2,000 alternations per minute. The current from the overhead trolley wire is normally fed in by one trolley at approximately 1,000 volts. Within the limits of the District of Columbia two trolleys are employed, as by Act of Congress the use of rails as conductors is prohibited in this District, presumably on account of electrolysis. In this

case the trouble, of course, will not exist, but the contracting company has been unable to obtain permission for the grounded circuit.

The alternating current to the car is carried through a main switch or circuit breaker on the car, to an auto-transformer connected between the trolley and the return circuit. At approximately 300 volts from the ground terminal a lead is brought out from the auto-transformer and passes through the regulator to one terminal of the motors. For starting and controlling the speed, an induction regulator is used with its secondary winding in series with the motors. This secondary circuit of the regulator can be made either to add to, or substract from the transformer voltage, thus raising or lowering the voltage

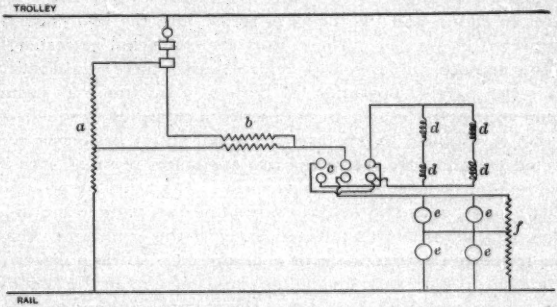

FIG. 1.—*a*. Auto-Transformer. *b*. Induction Regulator. *c*. Reversing Switch. *d*. Field of Motors. *e*. Armature of Motors. *f*. Equalizing Transformer.

supplied to the motors. The regulator therefore does double duty. The controller for D. C. motors merely lowers the voltage supplied to the motors but cannot raise it, but an A. C. regulator can be connected for an intermediate voltage, and can either raise or lower the motor voltage. In this way the regulator can be made relatively small, as it handles only the variable element of the voltage and the maximum voltage in the secondary winding is but half of the total variation required.

In the equipments in question, the range of voltage at the motor is to be varied from approximately 200 volts up to 400 volts or slightly higher. The transformer on the car will supply 315 volts, and the secondary circuit of the regulator will be

wound to generate slightly more than 100 volts when turned to the position of its maximum voltage. This voltage of the regulator is about one-fourth of that of the motors at full voltage. The regulator can consequently be made relatively small, in comparison with the motor capacity of the equipment. It has been found unnecessary to use much lower than 200 volts in this installation, as this allows a comparatively low running speed, and approximately 200 volts will be necessary to start with the required torque. The greater part of this voltage is necessary to overcome the e.m.f. of self-induction in the motor windings, which is dependent upon the current through the motor and is independent of the speed of the armature.

There will be four motors of 100 H.P. on each car. The full rated voltage of each motor is approximately 220 volts. The motors are arranged in two pairs, each consisting of two armatures in series, and two fields in series, and the two pairs are connected in parallel. The motors are connected permanently in this manner. Since voltage control is used, there is no necessity for series parallel operation, as with D. C. motors. To ensure equal voltage to the armatures in series, a balancing or equalizing action is obtained by the use of a small auto-transformer connected permanently across the two armatures in series with its middle point connected between them. The fields are arranged in two pairs, with two fields in series and two pairs in multiple. This parallels the fields independently of the armatures, which was formerly the practice with D. C. motors. It was a defective arrangement with such motors, as equal currents in the field did not ensure equal field strengths in the motors, and the armatures connected in parallel therefore would be operating in fields of unequal strength, with unequal armature currents as a direct result. With alternating currents in the fields, the case is different. The voltage across the fields is dependent upon the field strengths, and the current supplied to the fields naturally divides itself for equal magnetic strengths. The chief advantage in paralleling the fields and armatures independently is, that one reversing switch may serve for the four motors and one balancing transformer may be used across the two pairs of armatures. The ordinary D. C. arrangement of armatures in series with their own fields can be used, with a greater number of switches and connections.

The general arrangement of the auto-transformer, regulator, motors, etc., is shown in Fig. 1.

The induction regulator or controller, resembles an induction motor in general appearance and construction. The primary winding is placed on the rotor, and the secondary or low voltage winding on the stator. The rotor also has a second winding which is permanently short-circuited on itself. The function of this short-circuited winding is to neutralize the self-induction of the secondary winding as it passes from the magnetic influence of the primary. The regulator is wound for two poles, and therefore is operated through 180° in producing the full range of voltage for the motors. One end of the primary winding of the regulator is connected to the trolley, and the other to a point between the regulator and the motors. It thus receives a variable voltage as the controller is rotated. There are several advantages in this arrangement of the primary in this particular case. First, the regulator is worked at a higher induction at start, and at lower induction when running, the running position being used in these equipments for much longer periods than required for starting. Second, when the motors are operating at full voltage the current in the primary of the regulator passes through the motors but not through the auto-transformer or the secondary of the regulator. This allows considerable reduction in the size of auto-transformer and regulator.

The motors on the car are all of the straight series type. The armature and fields being connected in series, the entire current of the field passes through the armature as in ordinary series D. C. motors. The motor has eight poles, and the speed is approximately 700 revolutions at 220 volts. The general construction is similar to that of a D. C. motor, but the field core is laminated throughout, this being necessary on account of the alternating magnetic field. There are eight field-coils wound with copper strap, and all connected permanently in parallel. The parallel arrangement of field-coils assists in equalizing the field strength in the different poles, due to the balancing action of alternating circuits in parallel. This arrangement is not really necessary, but it possesses some advantages and therefore has been used. With equal magnetic strength in the poles, the magnetic pull is equalized even with the armature out of center.

The armature is similar in general construction to that of a D. C. motor. The fundamental difficulty in the operation of a commutator type of motor, on single-phase alternating current lies in the sparking at the brushes. The working current passing through the motor should be practically no more difficult

to commutate than an equal direct current, and it is not this current which gives trouble. The real source of trouble is found in a local or secondary current set up in any coil, the two ends of which are momentarily short-circuited by a brush. This coil encloses the alternating magnetic field, and thus becomes a secondary circuit of which the field-coil forms the primary. In

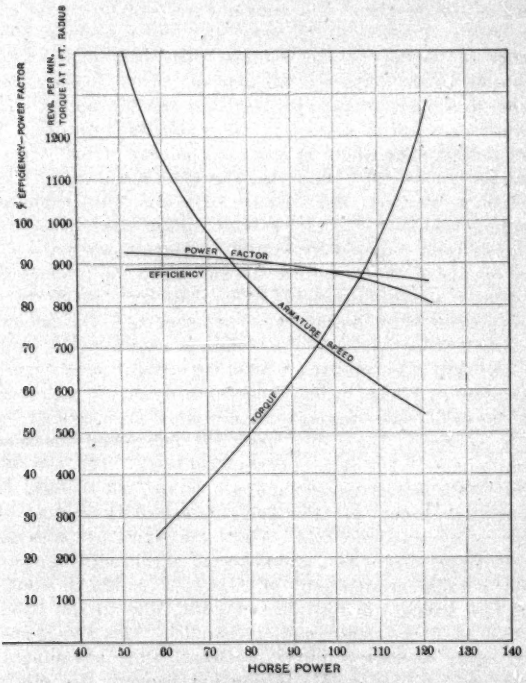

FIG. 2.—Westinghouse Alternating Current Railway Motor. No. 91.—Single-Phase.—220 Volts.

the motors of the Washington, Baltimore and Annapolis Railway, this commutation difficulty has been overcome by so constructing the motor that the secondary or short-circuit current in the armature coil is small, and the commutating conditions so

nearly perfect that the combined working and secondary currents can be commutated without sparking. This condition being obtained, the motor operates like a D. C. machine and will give no more trouble at the commutator than ordinary D. C. railway motors. Experience covering a considerable period in the operation of motors of 100 h.p. capacity indicates that no trouble need be feared at the commutator.

An extended series of tests were made with these motors at at the Westinghouse shops at East Pittsburg, both in the testing room and under a car. Fig. 2 shows curves of the speed, torque, efficiency and power factor plotted from data from brake tests.

It should be noted that the efficiency is good, being very nearly equal to that of high-class D. C. motors. The power factor, as shown in these curves, is highest at light loads and decreases with the load. This is due to the fact that the power developed increases approximately in proportion to the current, while the wattless component of the input increases practically as the square of the current. The curve indicates that the average power factor will be very good. The calculation for the W. B. and A. Railway show that the average power factor of the motors will be approximately 86 per cent.

The average efficiency of these equipments will be much higher during starting and accelerating than that of corresponding D. C. equipments, as rheostatic losses are avoided. When running at normal full speed, however, the efficiency will be slightly less than with D. C. This is due to the fact that the A. C. motor efficiency is slightly lower than the D. C., and in addition there are small losses in the transformer and the regulator. The A. C. equipments are somewhat heavier than the D. C., thus requiring some extra power, both in accelerating and at full speed. Therefore, for infrequent stops the D. C. car equipment is more efficient than the A. C., but for frequent stops the A. C. shows the better efficiency. Tests on the East Pittsburg track verified this conclusion. But the better efficiency of the D. C. equipment with infrequent stops is offset with the A. C. by decreased loss in the trolley wire, by reason of the higher voltage used, and by the elimination of the rotary converter losses. The resultant efficiency for the system will therefore be equal to or better than that of the D. C.

In the W. B. and A. Railway contract the guarantee given by the Westinghouse Electric and Mfg. Co. states that the efficiency of the system shall be equal to that of the D. C. system with rotary converter substations.

There is one loss in the A. C. system which is relatively much higher than in the D. C. This is the loss in the rail return. Tests have shown that at 2,000 alternations it is three to four times as great as with an equal direct current. This would be a serious matter in cases where the D. C. rail loss is high. But the higher A. C. trolley voltage reduces the current so much, that the A. C. rail loss is practically the same as with direct current at usual voltages. In many city railways the D. C. rail loss is made very low, not to lessen waste of power, but in order to reduce electrolysis. In such cases the A. C. rail loss could be higher than D. C., thus decreasing the cost of return conductors. More numerous transformer substations, with copper feeders connected to the rails at short intervals will enable the rail loss to be reduced to any extent desired.

As a frequency of 2,000 alternations per minute is used, the lighting of the cars and the substations was at first considered to be a serious difficulty, due to the very disagreeable winking of ordinary incandescent lamps at this frequency. Two methods of overcoming the winking were tried, both of which were successful. One method was by the use of split phase. A two-phase induction motor was run on a single-phase 2,000 alternating circuit, and current was taken from the unconnected primary circuit of the motor. This current was, of course, at approximately 90° from the current of the supply circuit. A two-phase circuit was thus obtained on the car. Currents from the two phases were put through ordinary incandescent lamps, placed close together. The resulting illumination a few feet distant from the lamps showed about the same winking as is noticed with 3,000 alts. With two filaments in one lamp the winking disappears entirely. A three-phase arrangement would work in the same way.

A much simpler method was tried which worked equally well. This consisted in the use of very low-voltage lamps. Low voltage at the lamp terminals allows the use of a thick filament with considerable heat inertia. Tests were made on lamps of this type at a frequency of 2,000 alts., and the light appeared to be as steady as that from the ordinary high-frequency incandescent lamp. The low voltage is not objectionable in this case, as a number of lamps can be run in a series, as in ordinary street railway practice, and any voltage desired can readily be obtained, as alternating current is used on the car.

There will be an air compressor, driven by a series A. C. motor, on each car, for supplying air to the brakes and for operating

the driving mechanism of the controller. The details of this mechanism are not sufficiently near to completion to permit a description of it. The method used will be one which readily allows operation on the multiple-unit system.

The generating station contains some interesting electrical features, but there is no great departure from usual A. C. practice. There will be three 1,500 K.W. single-phase alternators. These are 24-pole machines operating at 83 revolutions and wound for 15,000 volts at the terminals. They are of the rotating field type, with laminated magnetic circuits and field-coils of strap on edge. The field-coils are held on the poles by copper supports, which serve also as dampers to assist in the parallel running. The armatures are of the usual slotted type. The armature coils are placed in partially closed slots. There are four coils per pole. The proportions of these machines are such that good inherent regulation is obtained without saturation of the magnetic circuit. The rise in potential with non-inductive load thrown off will be approximately 4 per cent. An alternative estimate was furnished for the generators proposing 20,000 volts instead of 15,000. The simplicity of the type of winding used, and the low frequency, are both favorable for the use of very high voltage on the generator. As 15,000 volts was considered amply high for the service, the engineers for the railway considered it inadvisable to adopt a higher voltage.

There are to be two exciters, each of 100 K.W. capacity at 250 revolutions. The exciters are wound for 125 volts normal. The armature of each exciter has, in addition to the commutator, two collector rings, so that single-phase alternating current can be delivered. It is the intention to use the exciters as alternators for supplying current to the system for lighting when the large generators are shut down at night.

The main station switchboard comprises three generator panels, one load panel, and three feeder panels. High-tension oil-break switches are to be provided, operated by means of controlling apparatus on the panels. The switches, bus-bars and all high-tension apparatus will be in brick compartments separate from the board. In each generator circuit there are two non-automatic oil-break switches in series; and on each feeder circuit there are two overload time-limit oil-break switches in series. The two oil-break switches in series on the same circuit can be closed separately and then opened to test the switches without closing the circuit. With the switches in the closed position they are both operated

at the same time by the controlling apparatus, to ensure opening of the circuit, and to put less strain on the switches, although either one is capable of opening the load.

There will be nine transformer substations distributed along the railway line. Each station will contain two 250 K.W. oil-cooled lowering transformers, supplying approximately 1,000 volts to the trolley system. Two transformers are used in each station so that in case of accident to one transformer the station will not be entirely crippled.

It is the intention of the railway company to operate a D. C. road already equipped with the direct-current system. The present D. C. car equipments are to be retained, but the current will be supplied from a rotary converter substation fed from the main system of the W. B. and A. Railway. As this system is single-phase, it is necessary that single-phase rotaries be used in the substations. There are to be two 200 K.W. 550-volt rotary converters. These are 4-pole, 500-revolution machines. The general construction of these machines is very similar to that of the Westinghouse polyphase rotary converters. The armature resembles that of a polyphase rotary except in the number of collector rings, and in certain details of the proportions made necessary by reason of the use of single-phase. The commutating proportions are so perfect that any reactions due to the use of single-phase will result in no injurious effect. The field construction is similar to that of a polyphase rotary. The laminated field-poles are provided with dampers of the " grid " or " cage " type, a form used at present in the Westinghouse polyphase rotary converters. The dampers serve to prevent hunting, as in the polyphase machines, and also to damp out pulsations due to single-phase currents in the armature. The damper acts to a certain extent as a second phase. Each rotary converter is started and brought to synchronous speed by a small series A. C. motor on the end of the shaft. The voltage at the motor terminals can be adjusted either by loops from the lowering transformer or by resistance in series with the motor, so that true synchronous speed can be given to the rotary converter, before throwing it on the A. C. line.

From the preceding description of this system and the apparatus used on it, some conclusions may be drawn as to the various fields where it can be applied to advantage. It is evident that a good field for it will be on interurban long-distance lines such as the W. B. and A. Railway. On such railways, high trolley

voltage and the absence of converter substations are very important factors.

For heavy railroading also, this system possesses many ideal features. It allows efficient operation of large equipments at practically any speed and any torque, and also avoids the controller troubles which are ever present with large direct current equipments. It also permits the use of high trolley voltage, thus reducing the current to be collected. In this class of service the advantages of this A. C. system are so great that it is possible that heavy railroading will prove to be the special field for it.

For general city work, this system may not find a field for some time to come, as the limitations in the present system are not so great that there will be any urgent necessity for making a change. It is probable that at first it will be applied to new railways, or in changing over steam roads rather than in replacing existing city equipments. One difficulty with which the new system will have to contend, is due to the fact that the A. C. equipments cannot conveniently operate on existing D.C. city lines, as is the present practice where interurban lines run into the cities. It will be preferable for it to have its own lines throughout, unless very considerable complication is permitted. When the A. C. system applied to interurban and steam railways finally becomes of predominant importance, it is probable that the existing D. C. railways will gradually be changed to A. C. as a matter of convenience in tying the various lines together.

As was stated above, A. C. equipments cannot conveniently be operated on direct current lines. It does not follow, however, that the motor will not operate on direct current. On the contrary, the motor is a first-class direct current machine, and if supplied with suitable control apparatus and proper voltage it will operate very well on the D. C. lines. This would require that the motors be connected normally in series, as the voltage per motor is low. A complete set of D. C. control apparatus would be needed when the A. C. equipment is to be run on direct current, and considerable switching apparatus would be necessary for disconnecting all the A. C. control system and connecting in the D. C. The complication of such a system may be sufficient to prevent its use, at least for some time to come.

In some cities, very strict laws are in force in regard to the voltage variations in various parts of the track system. The

permissible variations are so small in some cases that an enormous amount of copper is used for return conductors; and in some cases special boosters are used in the return circuits to avoid large differences of potential between the various parts of the track system. The object in limiting the conditions in this manner is to avoid troubles from electrolysis. The A. C. system will, of course, remedy this.

For city work, it is probable that voltages of 500 or 600 would be employed instead of 1,000 or higher. The transformers and controllers can be designed to be readily changed from full to half voltage, so that low voltage can be used on one part of the line and high voltage on another. As the car equipments of such railways are usually of small capacity, it is probable that speed control will be obtained by means of a transformer with a large number of leads carried out to a control drum, rather than by means of the induction regulator, as the latter device is much more expensive in small units. This is chiefly a question of cost, and if the advantages of the induction regulator are found to over-weigh the objection of high first cost, then it will be used even on small equipments.

In the W. B. and A. Railway, the generators are wound for single-phase. In the case of large power-stations with many feeders, the generators may be wound for three-phase, with single-phase circuits carried out to the transformer substation; or three-phase transmission may be used, with the transformers connected in such a manner as will give a fairly well-balanced three-phase load.

There are many arrangements and combinations of apparatus made possible by the use of alternating current in the car equipments, which have not been mentioned, as it is impracticable to give a full description of all that can be done. But enough has been presented to outline the apparatus and to indicate the possibilities of this new system which is soon to see the test of commercial service.

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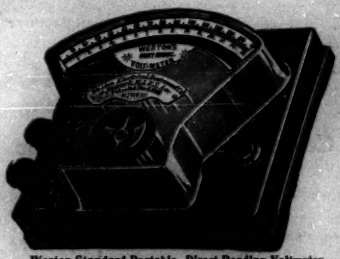

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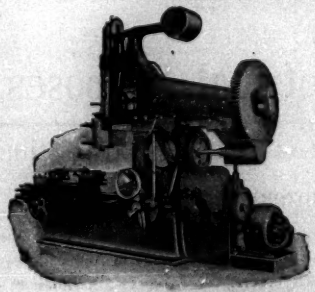

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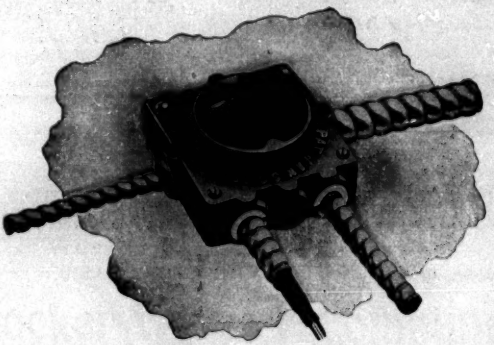

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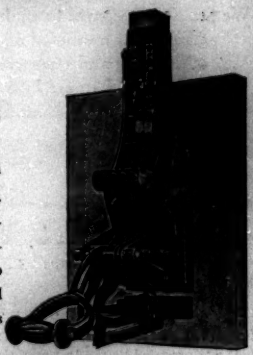

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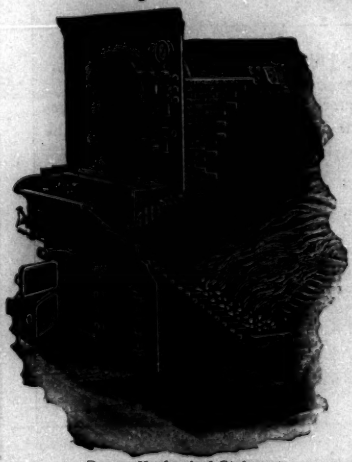

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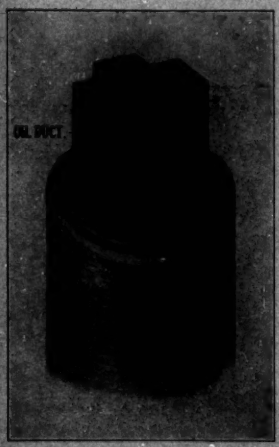

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